AN INVESTIGATION OF THE EFFECTS
OF TRANSOM STERN PARAMETERS
ON BARE HULL RESISTANCE FOR
DESTROYER TYPE SHIPS

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BY
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14 JUNE 1968

Dedicated to

our families

with whose patience

and understanding this thesis

was made possible.

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Mr. G. H. Smith

Mr. J. F. Rooney

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ABBREVIATIONS

Fn	Froude Number $0.298\ (V/\sqrt{L})$
Tt/Tx	Ratio of depth of transom on centre-line to draft at station of maximum area.
Tw/Bx	Ratio of width of transom on LwL to beam at station of maximum area.
Fa	Ordinate of non dimensional sectional area curve at AP (transom).
$\frac{LCB}{LWL}$	Position of LCB from forward perpendicular.
$\frac{LwL}{Bx}$	Length-beam ratio.
$\frac{Bx}{Tx}$	Beam-draft ratio.
Cp	Prismatic coefficient.
$\frac{\Delta}{(0.01Lwl)^3}$	Displacement-length coefficien t.
ie	Half angle of entrance on Lwl.
Cx	Area coefficient at station of maximum area.
$S = \frac{S}{\nabla^{2/3}}$	Wetted surface coefficient.
ib	Buttock slope at transom ¼ Tw buttock.
At	Area at transom (AP).
Cxt	Area coefficient at transom (AP).

$K = 0.5834 \quad V/\Delta^{1/6}$

$C = 2938 \quad Rt/\Delta^{2/3}\ V2$

where

Rt = Total resistance - tons

Δ = Displacement - tons (SW)

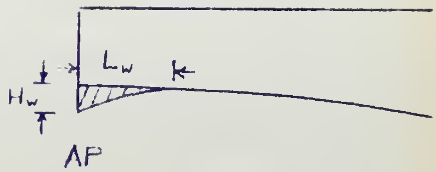
V = Speed - knots

Dimensionless form for any system of consistent units

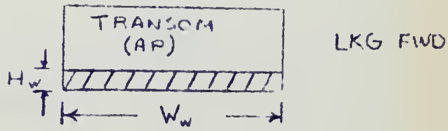
$$K = \sqrt{\frac{4\pi}{g}} \cdot \frac{V}{\Delta^{1/6}} \qquad C = \frac{1000Rt}{K^2}$$

L_w Length of transom wedge.

H_w Height of transom wedge.



W_w Width of transom wedge.



EHP Effective horsepower--bare hull--no skeg.

EHP_t Effective horsepower IAW - Taylor Series Reanalysis.

INTRODUCTION

This is an investigation into the design and testing in smooth water of various destroyer afterbody shapes based on a systematic variation of transom stern parameters. Apart from the U. S. Navy's one systematic experimental study on transom sterns conducted by the Naval Ship Research And Development Center (NSRDC) in 1932 (1), designers have been without satisfactory test data enabling them to predict optimum transom coefficients from the aspect of resistance and propulsion. Recently, however, for reasons of increased loading and unloading efficiency and stowage of unitized cargos, the transom stern is becoming economically desirable for modern high speed cargo ships. With this added interest MarAd (2) has embarked upon a model test program to cover the middle speed ranges $.26 < F_n < .4$ applicable to this type ship. The Admiralty Experimental Works Haslar (3) in 1966 conducted a comprehensive series of tank tests to provide design data for transom form variations among other parameters. This document is, however, restricted for official use only. It is the objective of the authors to add to this meager transom design information by an experimental study as it applies to high speed U. S. destroyer hull forms. By employing a regression analysis of resistance data for destroyer hulls derived by NSRDC (4), an additional objective will be to compare the predicted resistance

values to the experimental results. Investigations will also be made to determine if the regression analysis will predict resistance trends for transom variations outside the range of destroyer input data to the equation, as well as predict resistance for coefficients within the data input range.

The parent hull form selected for the subject tests was the DD 710 long hull destroyer. The basic form was maintained unchanged throughout the tests except for the various stern configurations. The parameters generally quoted for designs involving transom sterns have related one or more of the following dimensionless relationships: transom depth ratio (T_T/T_X), transom width ratio (T_W/B_X), transom area ratio (f_A), tangent at stern to the curve of dimensionless sectional area, and the aft buttock slope angle. The Admiralty has also included the apex angle of an equivalent semi-cone with a base at the transom and a height determined by fairing out the sectional area curve to zero aft of the transom and the distance between them, a phantom transom area ratio based on length, and the optimum LCB of the transom trough. Many of these parameters are inter-dependent, therefore, the number of coefficients to be investigated could be reduced. In order to isolate and measure the effect of transom variations between models of a series, one had to search for

stern coefficients that would significantly affect resistance on one hand but still not modify major hull form parameters in the process. This was attacked analytically with the aid of NSRDC's regression analysis of resistance data for destroyer models. By using the regression computer program to provide transom coefficients based on a merit comparison, plus existing reference material discussed elsewhere, the stern shapes reported herein were developed.

The immersed transom stern is generally inferior to the more common cruiser stern as far as resistance, speed and power are concerned until some critical speed is reached at which the water starts to clear the transom and leaves it's aft surface exposed to atmospheric pressure. This condition of having a region of low pressure just abaft the transom manifests its effect on resistance much the same as a bulbous bow. The influence of the transom on the stern wave hollow is similar to the effect of the bulbous bow on the bow wave crest, i.e., it increases the resistance at low speed and decreases it at high speed. At cruising speed and lower, experiments conducted by T. C. Gillmer (5) indicated that an immersed transom becomes a pressure drag generator whereby the depth of immersion is related directly to high eddy resistance and stern drag. As velocity is increased there is a progressive clearing and breaking away of the turbulent wake

from the entire submerged area of the transom which is reflected in decreased resistance.

The regression analysis indicated resistance to decrease significantly as transom width increased. With this information one could theoretically design a transom wide enough to prevent or reduce side flow separation at the waterline and shallow enough to reduce the low speed eddy resistance. It is realized that for a given sectional area curve a wider waterplane will result in increased wetted surface. It is believed, however, that the superior stern form at low speed and the wide plan~~n~~ing surface at high speeds provided with slightly hooked buttocks will more than offset this. It is the parameter transom-width that the authors have chosen to concentrate this investigation.

Though a wide stern is obviously poor for astern operation this was not considered an important design criterion. Various studies have shown on the other hand that a wide stern possesses some interesting advantages. Tests conducted at the Experimental Towing Tank, Stevens Institute, (6) showed that a wide destroyer transom with shallow immersion significantly reduced the turning diameter. With added area aft, the LCB shift aft also decreased the turning circle. The wide stern provided ample cover for the rudders thereby inhibiting rudder

breakdown and improving turning. Additional tests involving a comparison of transom deadrise showed that decreased deadrise usually associated with wide sterns gave the lowest resistance in the higher speed range. Recent work at NSRDC has also indicated that the shift of the longitudinal center of flotation (LCF) aft due to a wide stern with the resultant spread between LCF and LCB had some salutory effects regarding seakeeping.

THE SERIES

The major analytical source of information used in selecting the parameter variations was the NSRDC regression analysis. Considering the number of data points available (i.e. number of model tests), the number of terms in the final regression equation was limited to 49. The terms contained powers of the parameters up to the second, and products of two such terms, allowing eight parameters to be selected. Twelve parameters normally quoted for design purposes were listed in "order of significance", and eight were chosen considering practical aspects of the design problem. The terms are: ordinate of dimensionless sectional area curve at the AP (transom) - f_A; ratio of width of transom on the load waterline to the beam at the station of maximum area - T_W/B_X; half-angle of entrance on the load waterline - i_E; displacement-length ratio - $\Delta/(L_{WL}/100)^3$; prismatic coefficient - C_P; beam-draft ratio - B_X/T_X; length-beam ratio - L_{WL}/B_X; and the position of the LCB from the forward perpendicular - LCB/L_{WL}. The primary concern in the design of the first afterbody modification (model 2) was to hold constant the above non-transom coefficients, thereby isolating the effects of the transom stern variation. By modifying the afterbody only, the entrance angle (i_E) remained unchanged, and only slight changes resulted in L_{WL}/B_X and B_X/T_X due to fairing of the lines near the

maximum section at station 11. Displacement between models was held constant and varied plus and minus 10% to permit a greater amount of data for the small series. The C_P was likewise maintained constant with special attention to C_{PR}. The LCB, having a marked effect on resistance, was held constant by maintaining a constant transom area ratio and making as small changes as possible in the sectional area curve; see figure 1. With transom area held essentially constant and selecting a transom width ratio, the transom depth ratio can be determined mathematically as follows -

$$f_A = A_T/A_X \qquad A_X = C_X B_X T_X \qquad A_T = C_{XT} T_W T_T$$

then $$f_A = \frac{C_{XT} T_W T_T}{C_X B_X T_X} = \frac{C_{XT}}{C_X}(T_W/B_X)(T_T/T_X)$$

As seen by figure 2 for about 75 destroyer models plotted, f_A is essentially a straight line function of the product of the width and depth ratios. This means that for standard U.S. destroyers the C_{XT}/C_X is constant. Therefore, with f_A and T_W/B_X set T_T/T_X is known.

After testing the parent design, model 1, at its three displacements the following analysis was carried out to determine the first variation.

The initial step in the process involved investigation of the transom series conducted by NSRDC in 1932. Using the analysis for a two-way experimental layout

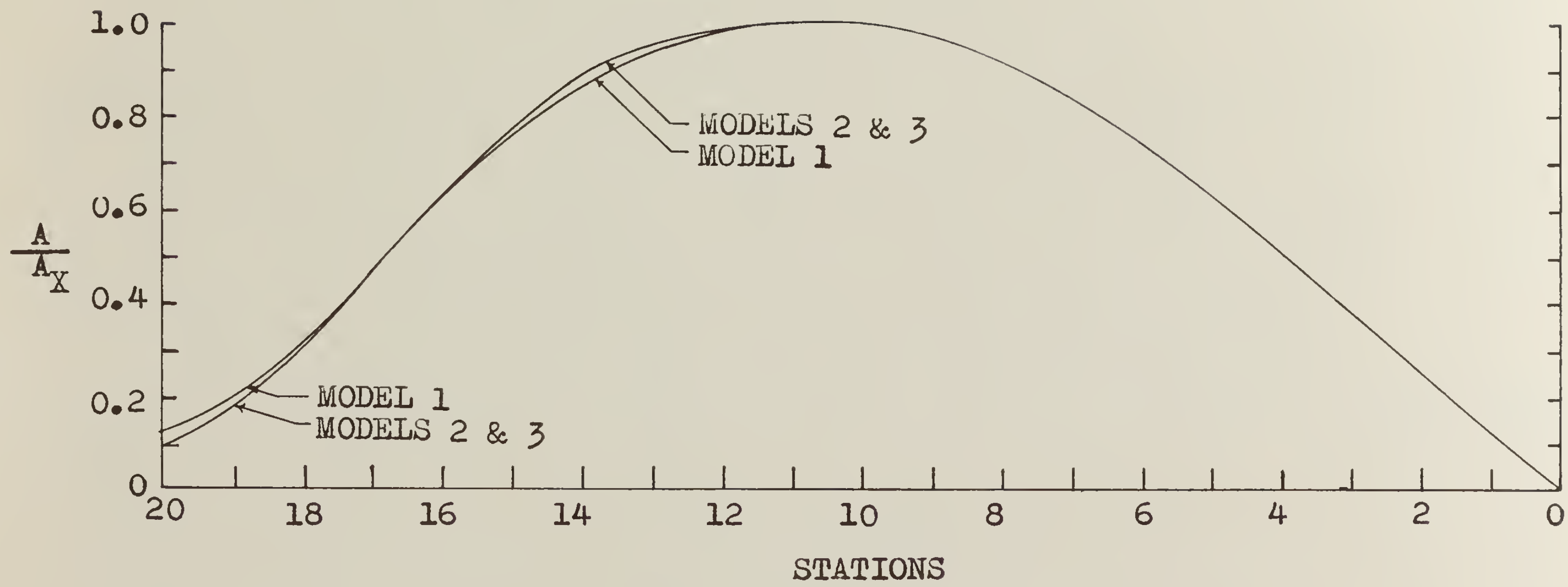


FIG-1 SECTIONAL AREA CURVES

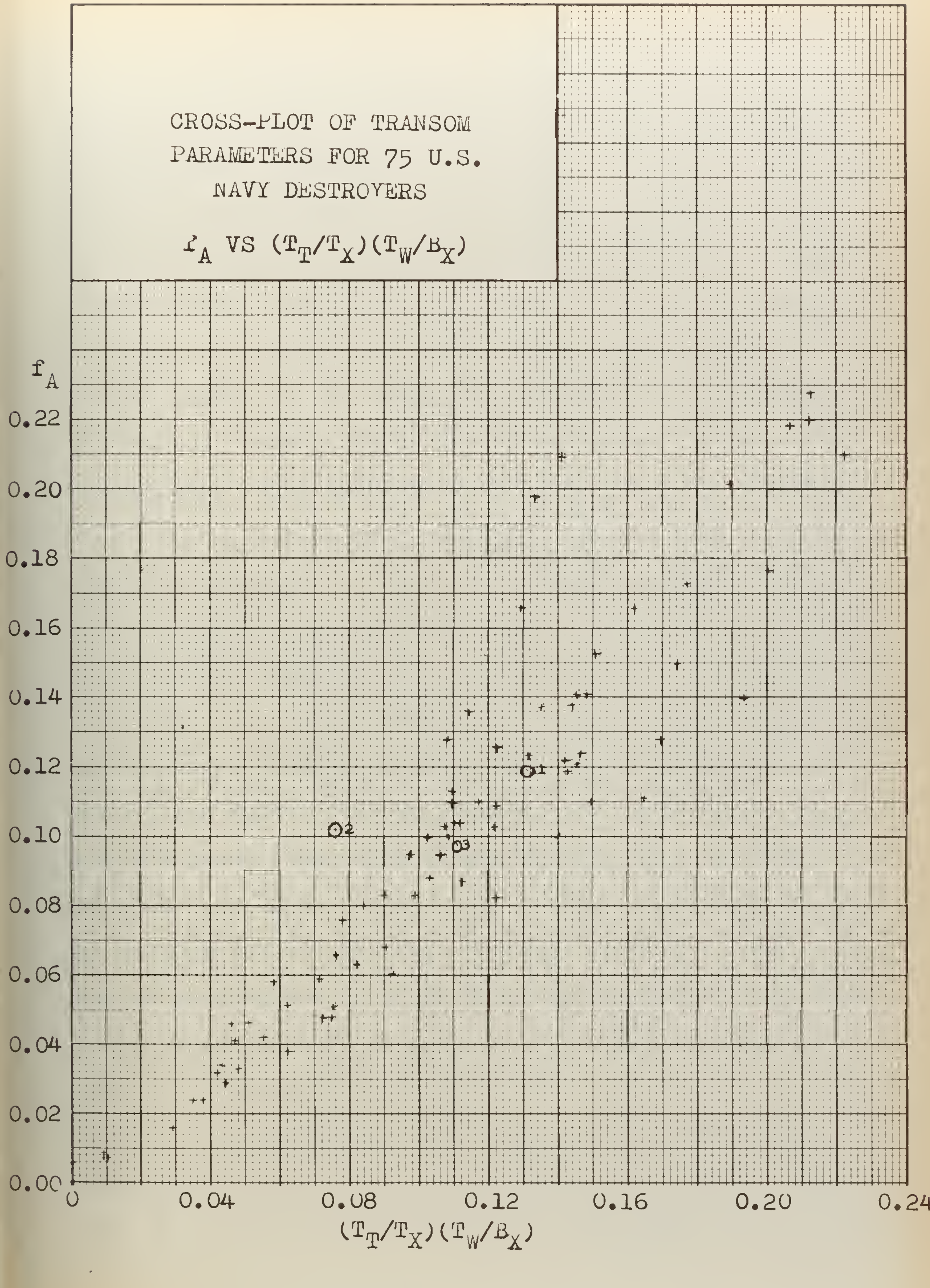

CROSS-PLOT OF TRANSOM
PARAMETERS FOR 75 U.S.
NAVY DESTROYERS
f_A VS $(T_T/T_X)(T_W/B_X)$
f_A
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
0.04
0.08
0.12
0.16
0.20
0.24
$(T_T/T_X)(T_W/B_X)$

FIG-2

with one observation per cell as outlined in Introduction to Engineering Statistics, by Guttman & Wilkes (7), see app. 1, resistance data presented in the NSRDC report was tested for significance. The results of the statistical study indicated that the transom area ratio was a significant parameter in resistance. The results also indicated that the shape of the sectional area curve at the transom (hollow, normal, full) had no significant effect on resistance. This would also indicated that the resulting buttock lines (hooked, straight, convex) have little effect on resistance. The authors felt, however, that hooked buttocks when employed with a wedge or flap deflecting the flow downward would have a beneficial effect on resistance. This was borne out to some degree by the testing done on several designs for the USCG 350 FT ocean-going cutter (8), which performed better with hooked buttocks than with straight buttocks. Hooked buttocks were used to some degree on all three models. The conclusions of the NSRDC report stated that for similar designs and at high design speeds ($V/\sqrt{L}$ = 1.7-2.0) the optimum f_A would be equal to approximately 10 per cent of the immersed midship section.

In order to verify this value for f_A additional study was conducted using the regression analysis. By using the input for the parent hull the change in

resistance as a function of f_A was evaluated at Ⓚ=2.4, 3.6, & 5.0 (ship speeds of 15.6, 23.4 & 32.5 knots). This curve, figure 3, verified the 1932 report to the extent that f_A = .08 - .10 was optimum and, therefore, f_A =0.10 was selected as the value to use for model 2 and model 3.

Similar plots, figures 4 & 5, were made to determine the effect on resistance of the variation of LCB and T_W/B_X. The objective in all these plots was to ascertain the parameters that indicate the greatest saving in resistance as well as compatibility of design. Even though LCB was not intended to be changed, small variations did occur when the lines were developed. Therefore, saving or increasing of resistance due to LCB was predicted to insure that its influence could be safely neglected. As previously mentioned the transom width ratio was chosen as the major design parameter. Figure 5 predicted the optimum transom width ratio to equal 1.0.

It should be pointed out at this time that the validity of the regression analysis equation is limited. In the first place, in order to be applicable the chosen form must have geometric parameters that are within the range of the original data. A less obvious limitation can arise if the data itself was not randomly distributed. If a plot of one parameter against the other shows a significant trend, then the method of analysis may

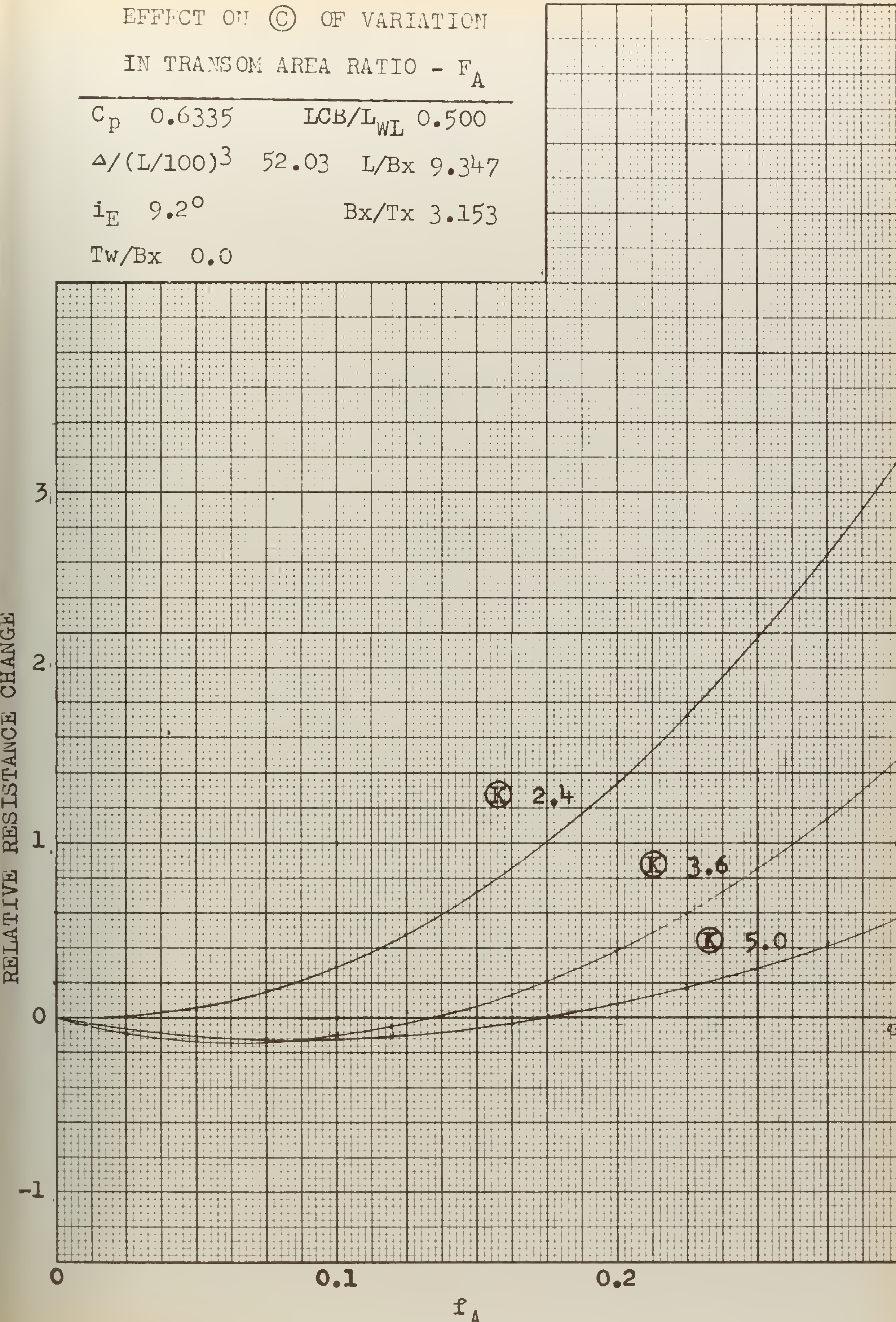

EFFECT ON © OF VARIATION IN TRANSOM AREA RATIO - F_A
C_p 0.6335
LCB/L_{WL} 0.500
$\Delta/(L/100)^3$ 52.03
L/Bx 9.347
i_E 9.2°
Bx/Tx 3.153
Tw/Bx 0.0
RELATIVE RESISTANCE CHANGE
3
2
1
0
-1
0
0.1
0.2
f_A
Ⓚ 2.4
Ⓚ 3.6
Ⓚ 5.0

FIG-3

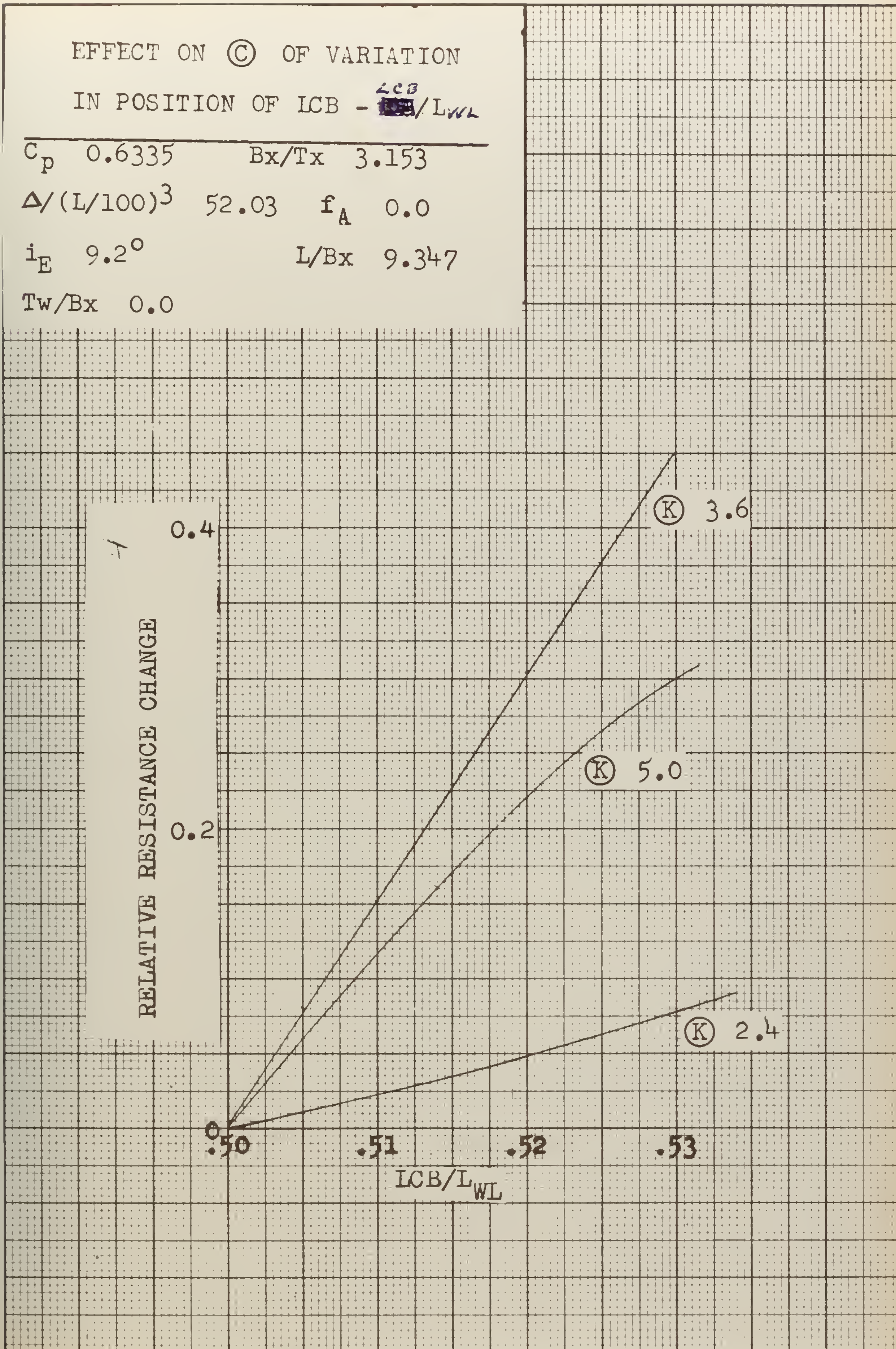

EFFECT ON © OF VARIATION
IN POSITION OF LCB - [redacted] LCB/L_WL
C_p 0.6335
Bx/Tx 3.153
Δ/(L/100)^3 52.03
f_A 0.0
i_E 9.2°
L/Bx 9.347
Tw/Bx 0.0
0.4
0.2
0
RELATIVE RESISTANCE CHANGE
Ⓚ 3.6
Ⓚ 5.0
Ⓚ 2.4
.50
.51
.52
.53
LCB/L_WL

FIG-4

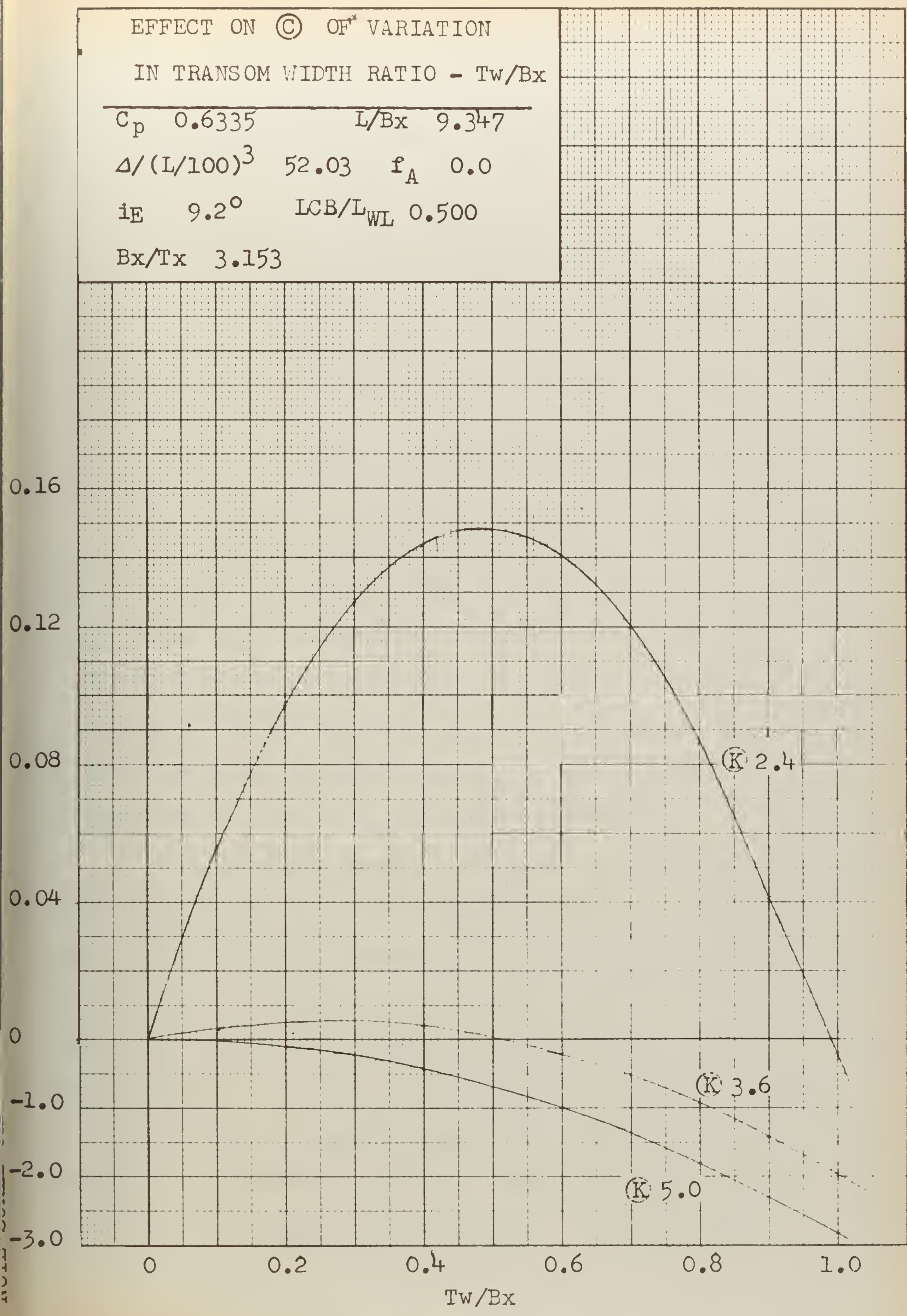

EFFECT ON © OF VARIATION
IN TRANSOM WIDTH RATIO - Tw/Bx
Cp 0.6335
L/Bx 9.347
Δ/(L/100)3 52.03
fA 0.0
iE 9.2°
LCB/LWL 0.500
Bx/Tx 3.153
0.16
0.12
0.08
0.04
0
-1.0
-2.0
-3.0
Ⓚ 2.4
Ⓚ 3.6
Ⓚ 5.0
0
0.2
0.4
0.6
0.8
1.0
Tw/Bx

FIG-5

falsely attribute an effect on resistance to one of them, when in fact it is due to the other, or even a third unknown parameter to which both are linked. The fact that such a correlation may exist means that although the derived equation gives the best least-squares fit to the input data, an error will result when used to estimate performances of a novel form. It would therefore be misleading to attempt to deduce any real significance from the magnitude and sign of the coefficients that would be used in the regression equation. On the other hand, even though resistance magnitudes may not be predicatable, it is conceivable that qualitative trend information may be realized. It is for this reason that a $T_W/B_X = 1.0$ was selected for model 2, rather than rejected as being an unreliable data point as might be suggested by plot of f_A vs T_W/B_X, figure 6.

A statistical analysis predicting resistance of destroyers and frigates written jointly by N. Blomfield and J. Foster of Portsmouth College of Technology and the Admiralty Experimental Works at Haslar (9) actually plotted their hull parameters against each other and showed them to be free of interaction. Figures 2 and 6 thru 10 were similarly plotted for the transom parameters in question as well as their cross products to determine any parameter dependence. The selected

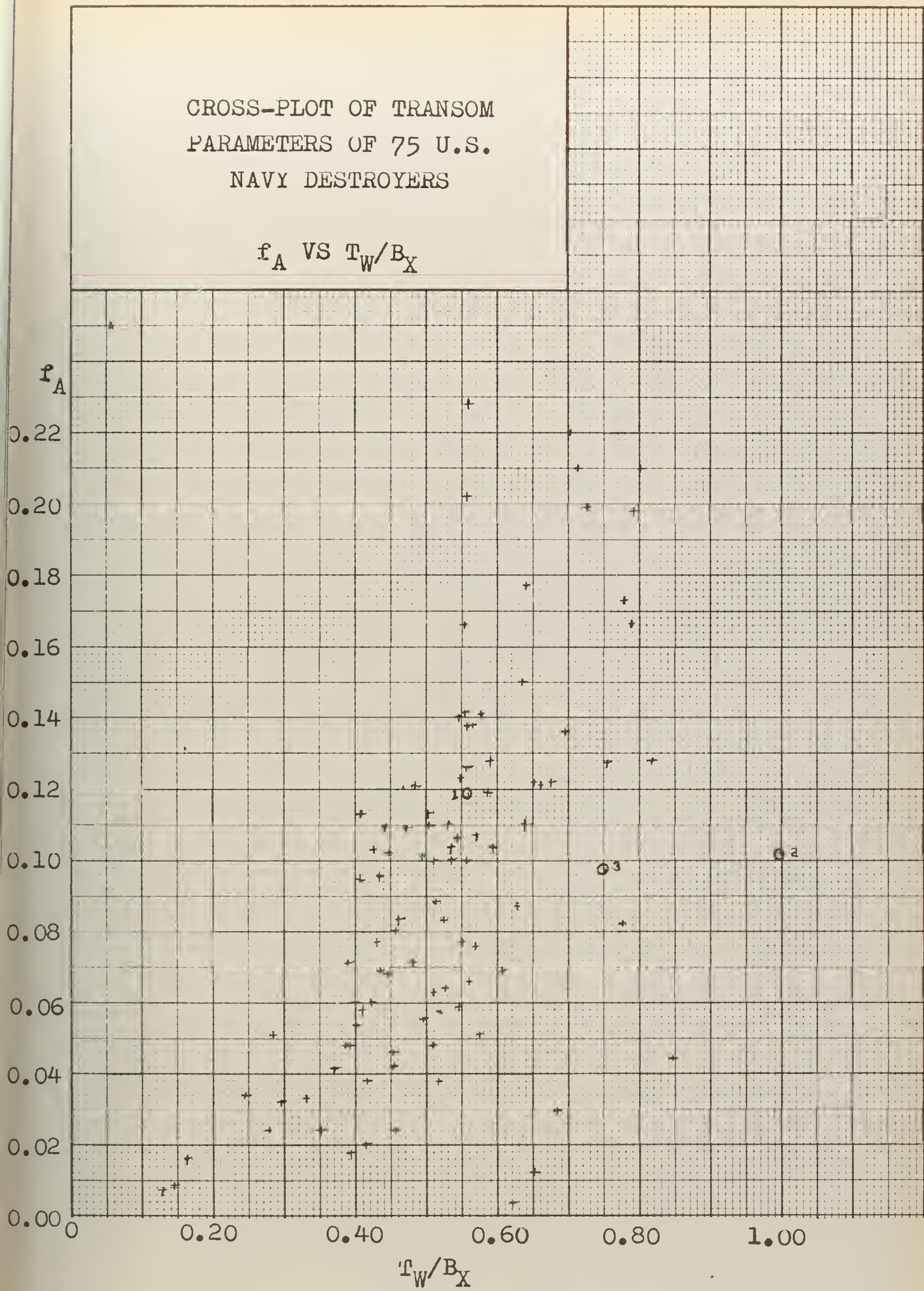

CROSS-PLOT OF TRANSOM PARAMETERS OF 75 U.S. NAVY DESTROYERS
f_A VS T_W/B_X
f_A
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
0.20
0.40
0.60
0.80
1.00
T_W/B_X
1
3
2

FIG-6

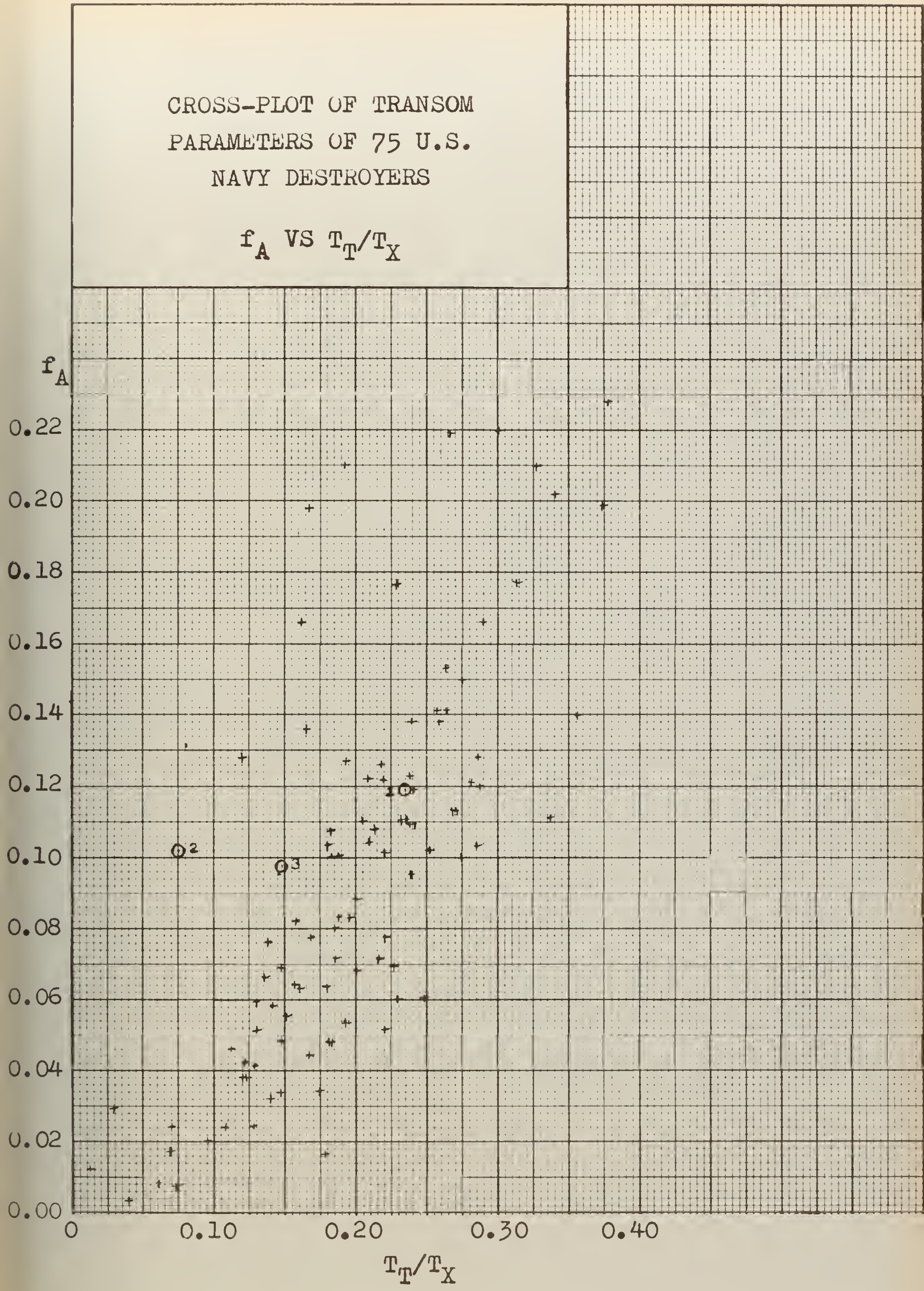

CROSS-PLOT OF TRANSOM
PARAMETERS OF 75 U.S.
NAVY DESTROYERS
f_A VS T_T/T_X
f_A
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
0.10
0.20
0.30
0.40
T_T/T_X
1
2
3

FIG-7

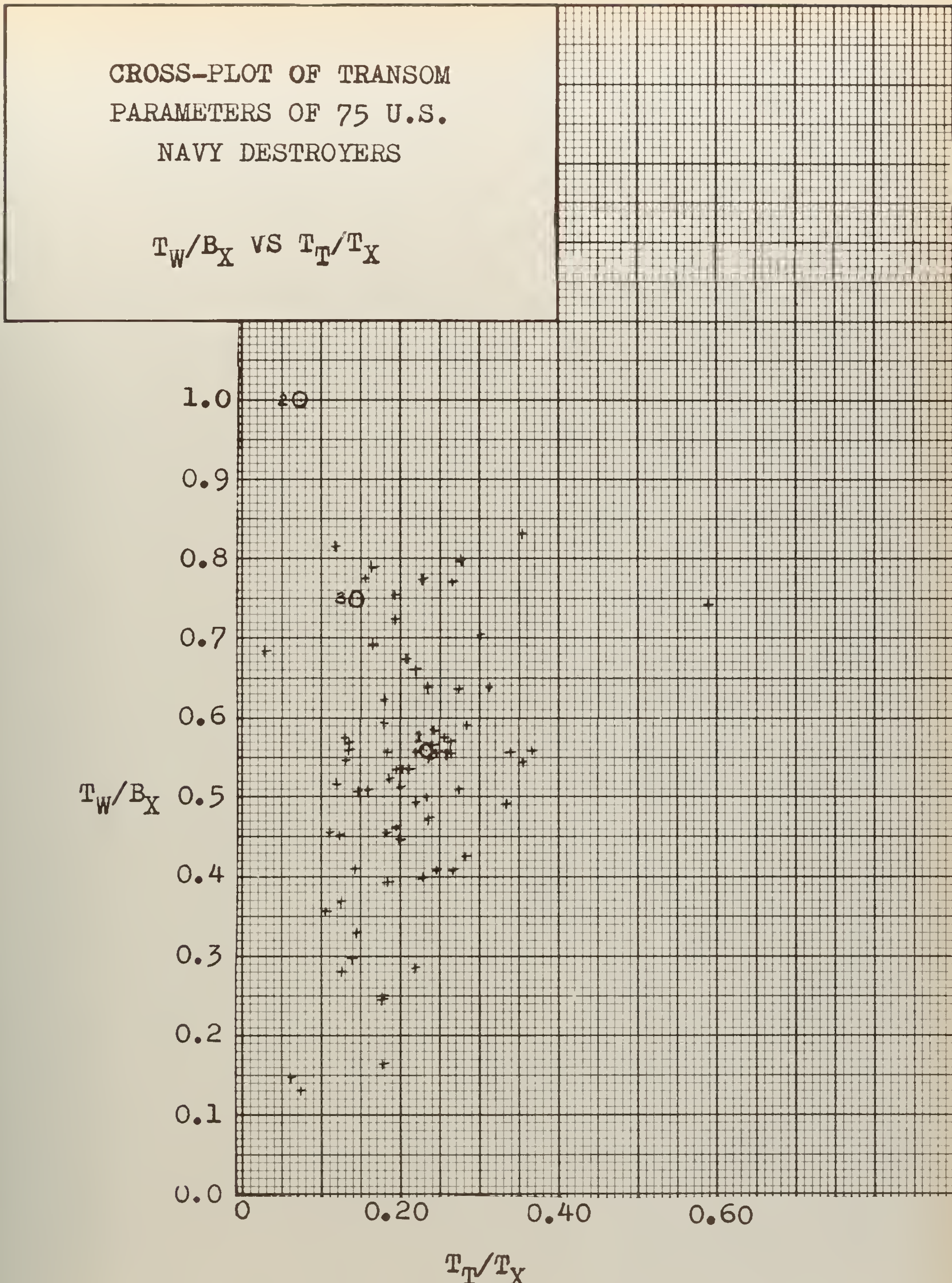

CROSS-PLOT OF TRANSOM PARAMETERS OF 75 U.S. NAVY DESTROYERS
T_W/B_X VS T_T/T_X
1.0
0.9
0.8
0.7
0.6
T_W/B_X 0.5
0.4
0.3
0.2
0.1
0.0
0
0.20
0.40
0.60
T_T/T_X

FIG-8

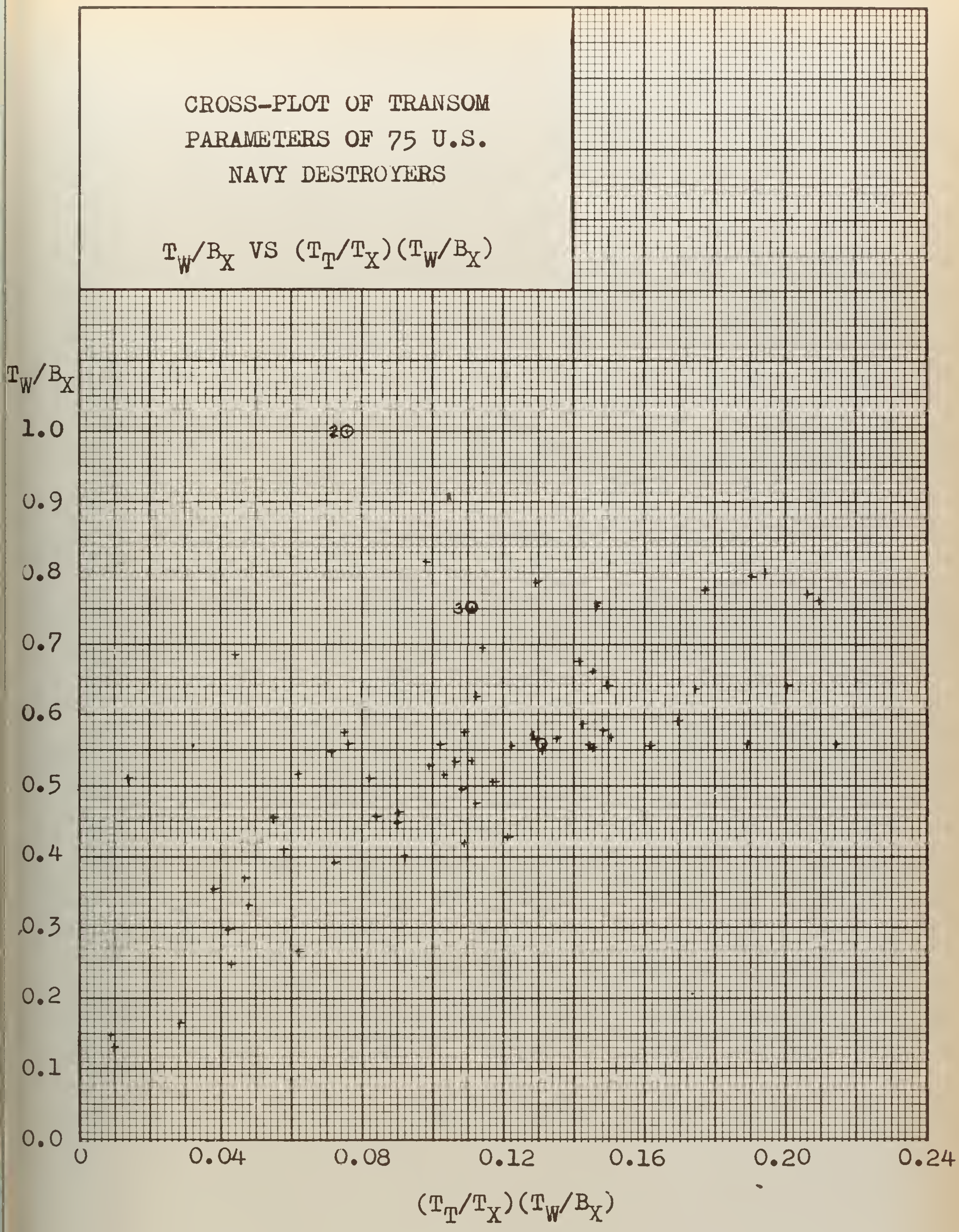

CROSS-PLOT OF TRANSOM
PARAMETERS OF 75 U.S.
NAVY DESTROYERS
T_W/B_X VS (T_T/T_X)(T_W/B_X)
T_W/B_X
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
0.04
0.08
0.12
0.16
0.20
0.24
(T_T/T_X)(T_W/B_X)

FIG-9

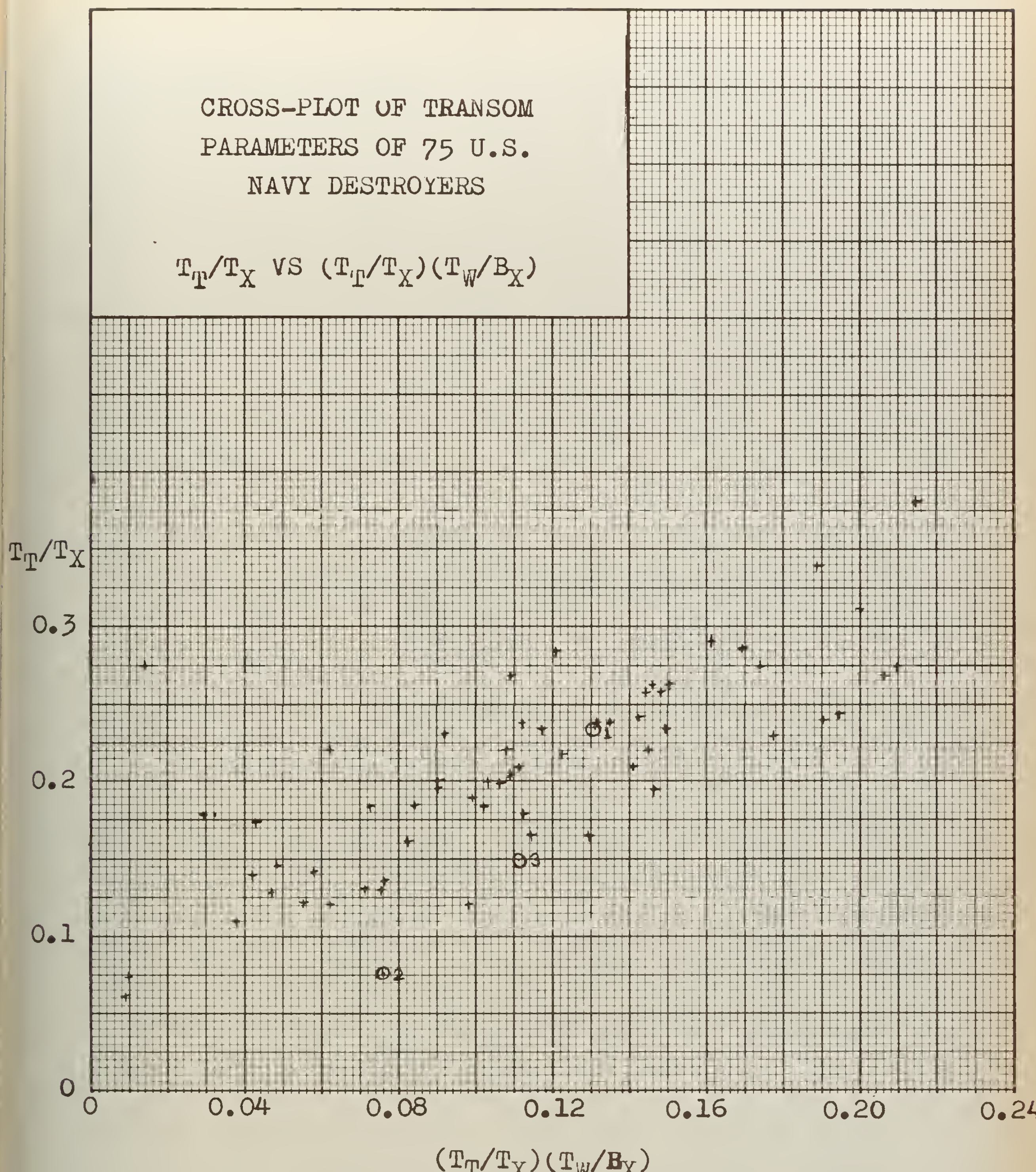

CROSS-PLOT OF TRANSOM PARAMETERS OF 75 U.S. NAVY DESTROYERS
T_T/T_X VS $(T_T/T_X)(T_W/B_X)$
T_T/T_X
0.3
0.2
0.1
0
0.04
0.08
0.12
0.16
0.20
0.24
1
2
3
$(T_T/T_X)(T_W/B_X)$

FIG-10

coefficients for the three models are plotted for comparison. The only significant trend was found in f_A vs $(T_W/B_X)(T_T/T_X)$, figure 2, as previously mentioned. These plots now permitted a qualitative prediction of savings in resistance due to the selected coefficients using figures 3 & 5, and allowed superposition of the results to reflect an overall saving due to their independence. This is shown in table 1 below.

TABLE 1

Form variation at the design displacement

Coef	model 1	model 2
T_W/B_X	0.558	1.000
f_A	0.119	0.100

Predicted resistance decrease for model 2

Ship Speed Kts	K	due to T_W/B_X	due to f_A	total	actual model 2
16	2.4	- 1.94%	-1.75%	- 3.69%	+6.80%
24	3.6	-19.00	-0.49	-19.49	-0.10
33.2	5.0	-13.10	-0.20	-13.30	-3.00

The procedure used to determine the coefficients for model 3 also used the output from the regression equation, figures 3 thru 5. The area ratio was once again maintained at 10% of the immersed midship section to allow comparison between all models at design displacement. The forebody and displacement coefficients were held constant and equal to models 1 and 2 with no appreciable LCB shift. The criteria for selecting the remaining

coefficient, T_W/B_X, was two fold: first, a significant saving in resistance was desired, and second, the choice of the coefficient should fall within the range of input data to the regression equation, to allow a more meaningful prediction of resistance. A $T_W/B_X = .75$ was selected to satisfy the above criteria, falling within the outer limits of the regression equation with a predicted resistance saving equal to that achieved by model 2 (see table 2). Therefore model 3 was designed as a mean between the two previous hulls.

TABLE 2

Form variation at the design displacement

Coef	Model 1	Model 2	Model 3
T_W/B_X	0.558	1.000	0.750
f_A	0.119	0.102	0.100

Predicted resistance decrease for model 3

Ship Speed Kts	K	due to T_W/B_X	due to f_A	Total	Actual model 2	Actual model 3
15.6	2.4	-0.47%	-1.75%	-2.22%	+6.80%	+5.70%
23.5	3.6	-0.56	-0.49	-1.05	-0.10	+2.20
32.5	5.0	-4.97	-0.20	-5.17	-3.00	-2.50

The body plans and coefficients for the three models of the series are shown in Tables 3 thru 5 and figures 11 thru 13. Each model was tested at the 13 FT design waterline without trim and at 10% increased and 10% decreased displacement. The coefficients are shown for

each waterline of each model. The design WL and stern profile for each model is shown in figure 14.

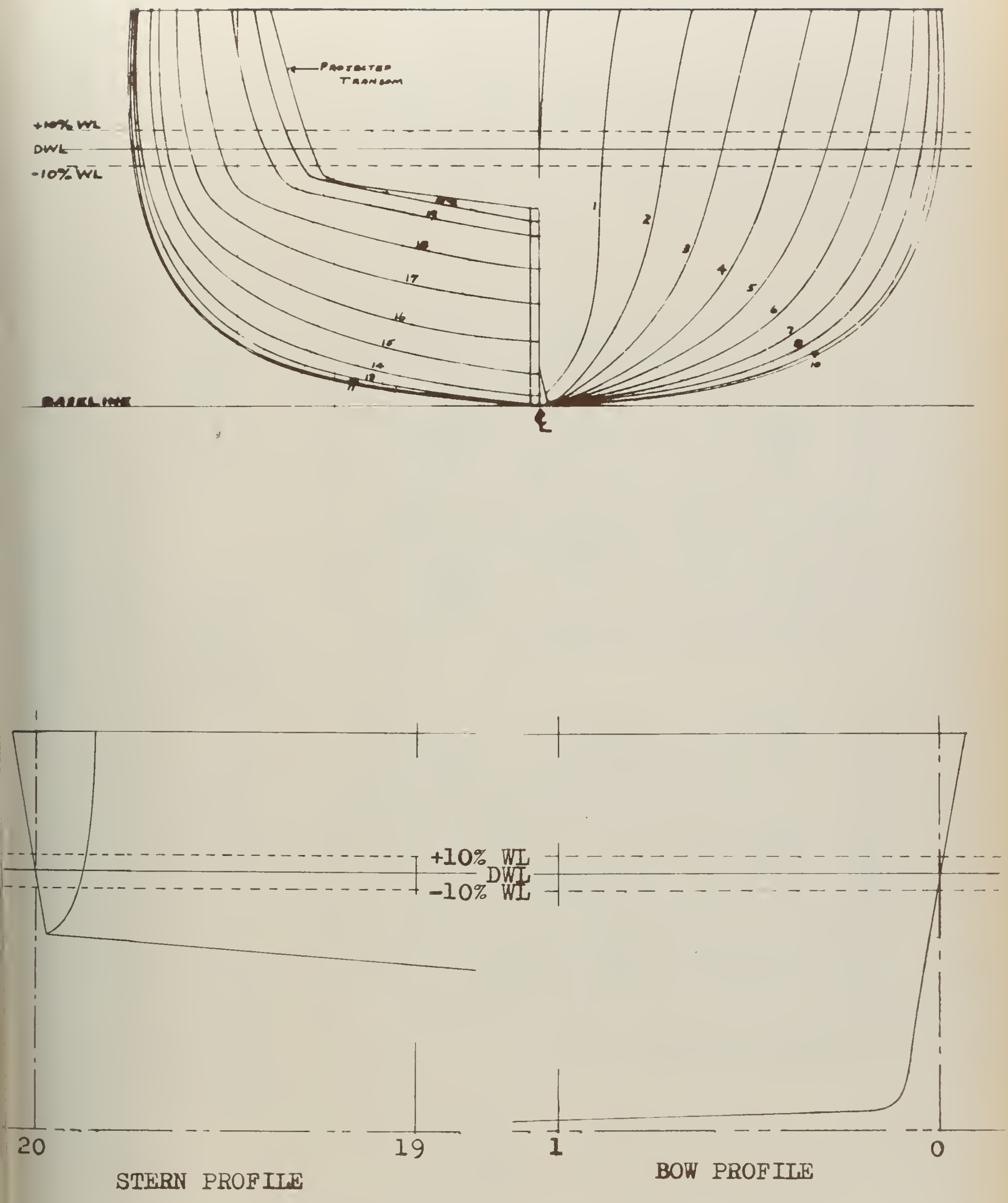


FIG-11 MODEL 1 BODY PLAN & BOW & STERN PROFILES

SHIP AND MODEL DATA
FOR

MODEL 1

	SHIP	MODEL
LENGTH (LWL) FT	383.0 FT	53.93 IN
LENGTH (LBP) FT	383.0 FT	53.93 IN

APPENDAGES: NONE

WL ENTRANCE HALF ANGLE = 9.2^{0}

λ = 85.225 $V/\sqrt{L_{LWL}}$ =

	-10% DISPLACEMENT SHIP	-10% DISPLACEMENT MODEL	DESIGN DISPLACEMENT SHIP	DESIGN DISPLACEMENT MODEL	+10% DISPLACEMENT SHIP	+10% DISPLACEMENT MODEL
BEAM (B_x) FT	40.8 FT	5.75 IN	41.0 FT	5.77 IN	41.1 FT	5.79 IN
DRAFT (T_x) FT	12.1 FT	1.71 IN	13.0 FT	1.83 IN	13.8 FT	1.95 IN
DISPL. IN TONS	2706 S.W.	9.52 lbF.W.	3007 S.W.	10.58 lbFW	3308 S.W.	11.64 lbFW
WETTED SURF. SQ. FT.	15,936	2.194	16,553	2.279	17,199	2.368

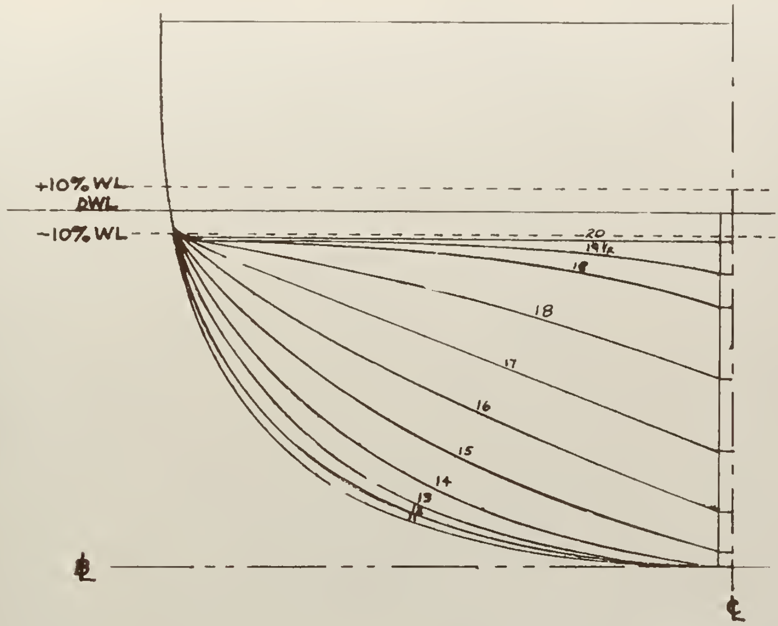
LWL COEFFICIENTS

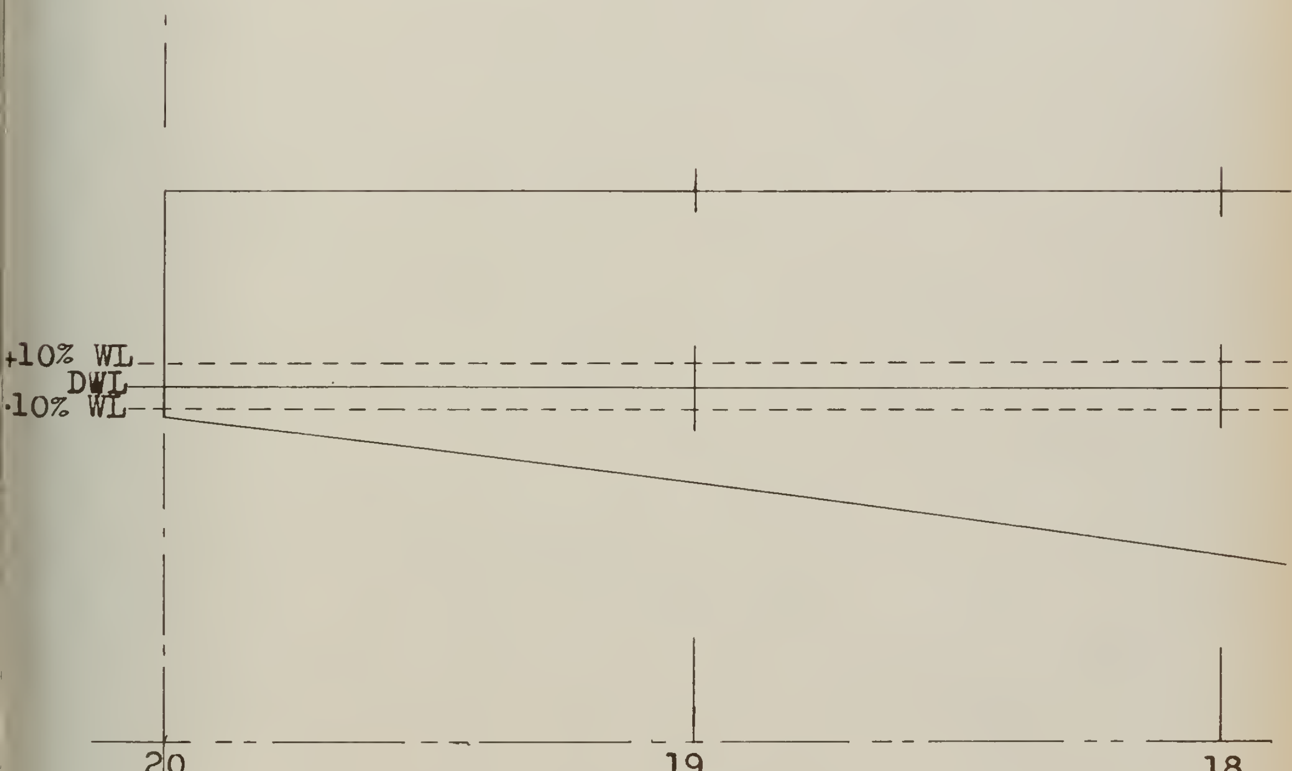
	-10%			Design			+10%	
C_B	0.498	C_{WF} 0.635	C_B	0.516	C_{WF} 0.639	C_B	0.530	C_{WF} 0.645
C_P	0.620	C_{WA} 0.897	C_P	0.635	C_{WA} 0.904	C_P	0.644	C_{WA} 0.906
C_X	0.804	L_E/L 0.550	C_X	0.813	L_E/L 0.550	C_X	0.822	L_E/L 0.550
C_W	0.753	L_P/L 0.000	C_W	0.759	L_P/L 0.000	C_W	0.765	L_P/L 0.000
C_{PF}	0.579	L_R/L 0.450	C_{PF}	0.592	L_R/L 0.450	C_{PF}	0.598	L_R/L 0.450
C_{PA}	0.660	L/B_X 9.379	C_{PA}	0.681	L/B_X 9.347	C_{PA}	0.700	L/B_X 9.314
C_{PE}	0.186	B_X/T_X 3.363	C_{PE}	0.189	B_X/T_X 3.153	C_{PE}	0.192	B_X/T_X 2.969
C_{PR}	0.126	$\Delta/(0.01L)^3$ 46.82	C_{PR}	0.131	$\Delta/(0.01L)^3$ 52.03	C_{PR}	0.134	$\Delta/(0.01L)^3$ 57.25
C_{PV}	0.662	$S/\sqrt{\Delta L}$ 15.65	C_{PV}	0.680	$S/\sqrt{\Delta L}$ 15.42	C_{PV}	0.692	$S/\sqrt{\Delta L}$ 15.28
C_{PVA}	0.600	$LCB/_{LWL}$ = 0.516	C_{PVA}	0.620	$LCB/_{LWL}$ = 0.518	C_{PVA}	0.641	$LCB/_{LWL}$ = 0.522
C_{PVF}	0.744		C_{PVF}	0.762		C_{PVF}	0.769	

TRANSOM COEFFICIENTS

	-10%		Design		+10%	
f_A	0.081		0.119		0.153	
T_W/B_X	0.543	$\frac{LCF}{LWL}$ 0.560	0.558	$\frac{LCF}{LWL}$ 0.561	0.570	$\frac{LCF}{LWL}$ 0.560
T_T/T_X	0.181		0.235		0.282	

TABLE 3





TRANSOM PROFILE

FIG-12 MODEL 2 BODY PLAN
& STERN PROFILE

MODEL [illegible]

	SHIP	MODEL
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

APPENDAGES [illegible]
∇ ENTRANCE [illegible] [illegible]
Δ 85,225

-[illegible] DISPLACEMENT

SHIP	MODEL
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]

W.L. COEFF. [illegible]

[illegible] DISPLACEMENT

SHIP	MODEL
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]

W.L. COEFFICIENTS

C_B	0.516	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0.616	[illegible]	[illegible]
[illegible]	0.614	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0.578		

[illegible] COEFFICIENTS

[illegible]	[illegible]
[illegible]	1.000
[illegible]	0.078

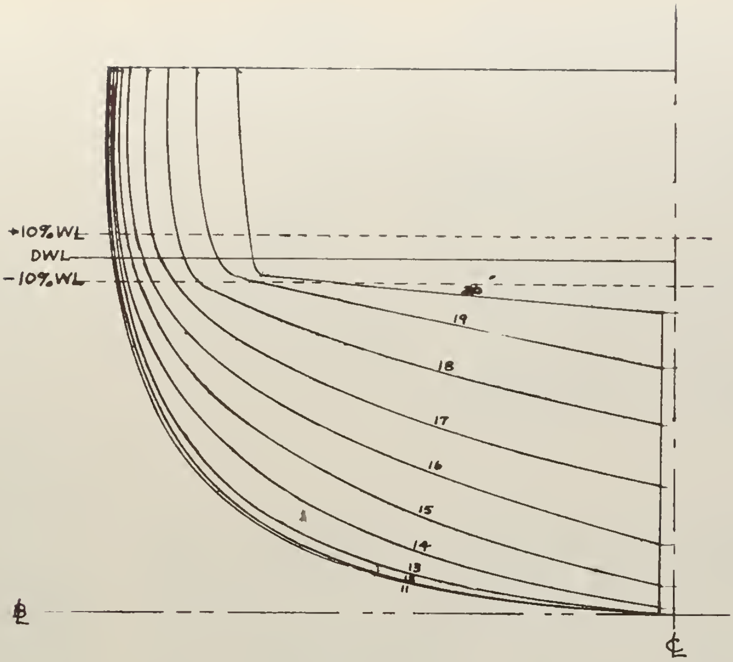
+ [illegible] DISPLACEMENT

SHIP	MODEL
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]

W.L. COEFFICIENTS

[illegible] COEFFICIENTS

[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	0.134



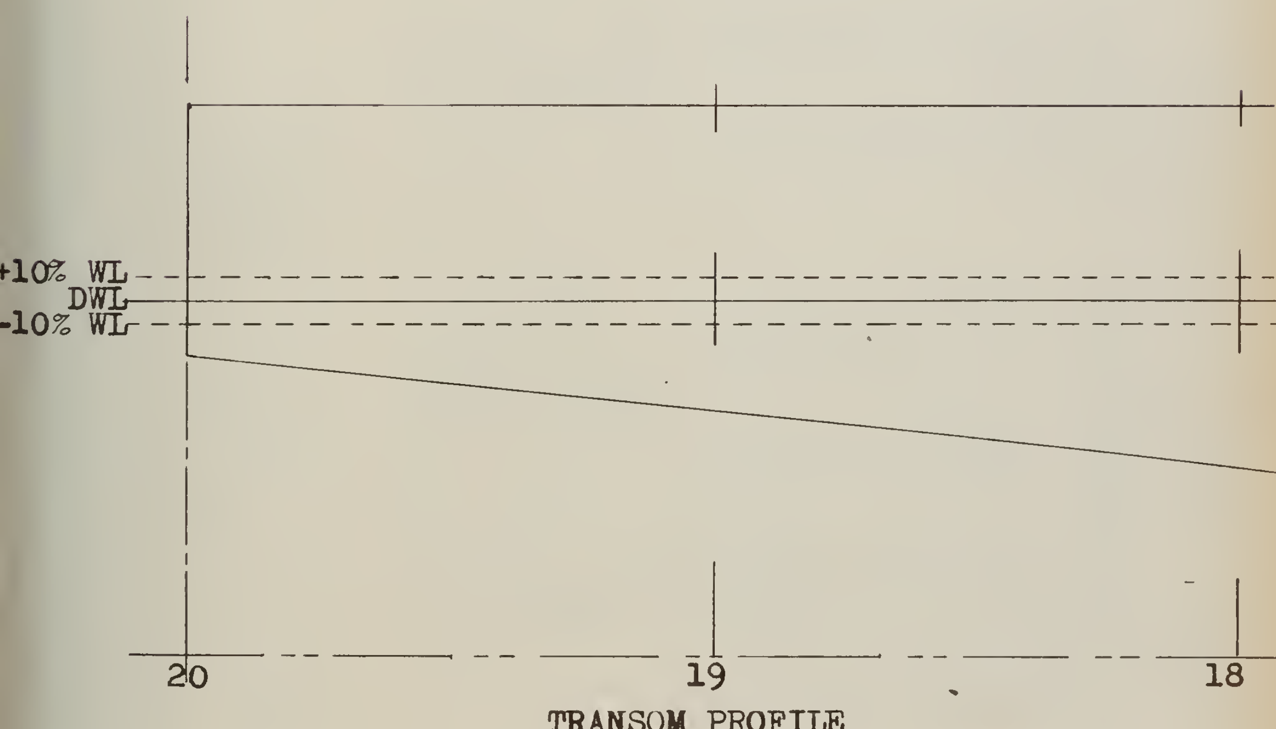


FIG-13 MODEL 3 BODY PLAN
& STERN PROFILE

SHIP AND MODEL DATA
FOR

MODEL 3

	SHIP	MODEL
LENGTH (LWL) FT	383.0 FT	53.93 IN
LENGTH (LBP) FT	383.0 FT	53.93 IN

APPENDAGES: NONE

WL ENTRANCE HALF ANGLE = 9.2°

λ = 85.225

	-10% DISPLACEMENT		DESIGN DISPLACEMENT		+10% DISPLACEMENT	
	SHIP	MODEL	SHIP	MODEL	SHIP	MODEL
BEAM (B_X) FT	40.75FT	5.74 IN	41.0 FT	5.77 IN	41.2 FT	5.80 IN
DRAFT (T_X) FT	12.1 FT	1.71 IN	13.0 FT	1.83 IN	13.8 FT	1.95 IN
DISPL. IN TONS	2706 S.W.	9.52 lb F.W.	3007 S.W.	10.58 lb F.W.	3308 S.W.	11.64 lb F.W.
WETTED SURF. SQ. FT.	16,263	2.239	16,931	2.331	17,592	2.422

-10% DISPLACEMENT — LWL COEFFICIENTS

C_B	0.500	C_{WF}	0.635
C_P	0.618	C_{WA}	0.931
C_X	0.808	L_E/L	0.550
C_W	0.771	L_P/L	0.000
C_{PF}	0.579	L_R/L	0.450
C_{PA}	0.660	L/B_X	9.395
C_{PE}	0.185	B_X/T_X	3.357
C_{PR}	0.125	$\Delta/(.01L)^3$	46.82
C_{PV}	0.648	$S/\sqrt{\Delta L}$	15.97
C_{PVA}	0.578	LCB/LWL =	0.515
C_{PVF}	0.716		

TRANSOM COEFFICIENTS

f_A	0.038		
T_W/B_X	0.617	$\frac{LCF}{LWL}$	0.561
T_T/T_X	0.088		

DESIGN DISPLACEMENT — LWL COEFFICIENTS

C_B	0.516	C_{WF}	0.639
C_P	0.632	C_{WA}	0.952
C_X	0.816	L_E/L	0.550
C_W	0.783	L_P/L	0.000
C_{PF}	0.592	L_R/L	0.450
C_{PA}	0.681	L/B_X	9.347
C_{PE}	0.188	B_X/T_X	3.153
C_{PR}	0.130	$\Delta/(.01L)^3$	52.03
C_{PV}	0.658	$S/\sqrt{\Delta L}$	15.78
C_{PVA}	0.588	LCB/LWL =	0.518
C_{PVF}	0.732		

TRANSOM COEFFICIENTS

f_A	0.098		
T_W/B_X	0.750	$\frac{LCF}{LWL}$	0.570
T_T/T_X	0.148		

+10% DISPLACEMENT — LWL COEFFICIENTS

C_B	0.530	C_{WF}	0.645
C_P	0.644	C_{WA}	0.955
C_X	0.823	L_E/L	0.550
C_W	0.788	L_P/L	0.000
C_{PF}	0.598	L_R/L	0.450
C_{PA}	0.700	L/B_X	9.298
C_{PE}	0.191	B_X/T_X	2.974
C_{PR}	0.134	$\Delta/(.01L)^3$	57.25
C_{PV}	0.673	$S/\sqrt{\Delta L}$	15.63
C_{PVA}	0.608	LCB/LWL =	0.523
C_{PVF}	0.729		

TRANSOM COEFFICIENTS

f_A	0.147		
T_W/B_X	0.755	$\frac{LCF}{LWL}$	0.570
T_T/T_X	0.200		

TABLE 5

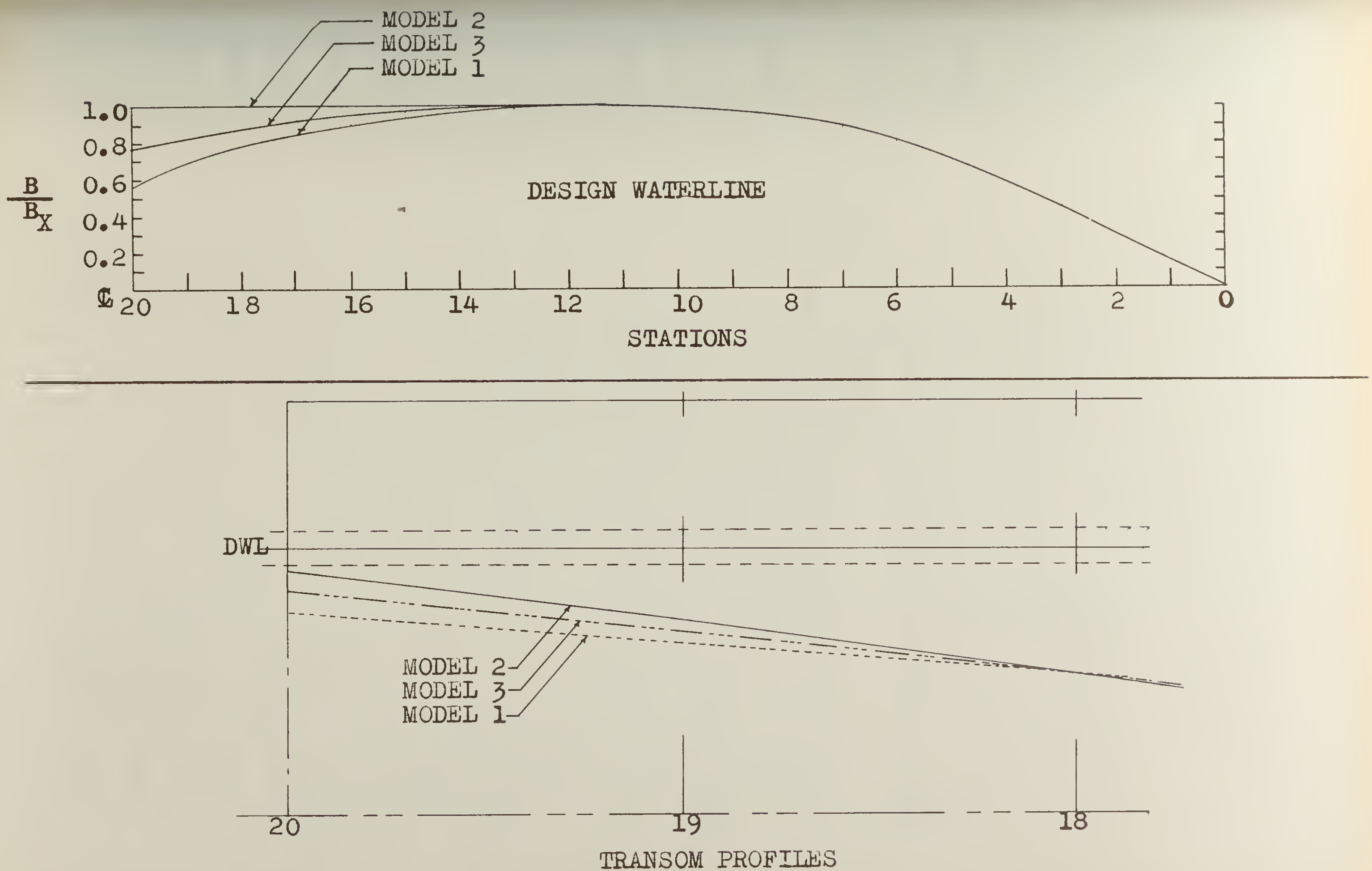


FIG-14 DESIGN WATERLINES & STERN PROFILES

WEDGE DESIGN

A search of the literature revealed that one additional method of reducing afterbody resistance was by application of wedges attached to or flaps mounted aft of the transom. It was decided to design a wedge rather than the flap due to the limited scope of the study. This meant the selected wedge would be optimum at one speed and trim condition, whereas a flap or adjustable wedge could be optimized at various slopes throughout the speed range.

It is possible to combine an analytical and experimental approach to determining wedge size. It is common knowledge that ships such as destroyers "squat" at high speeds. Admiral Taylor (10) attributes the marked increase in resistance and change in trim above $V/\sqrt{L} = 1.2$ to an excessive bow wave and deep first wave hollow. It is possible to reduce this trim change by a lifting device at the stern. This was investigated by LTs Nelson and Greene in a Master's Thesis at Webb Institute in 1955 (11). A method was devised in that thesis to experimentally measure the reduction of resistance of a destroyer for a given vertical force up on the stern. The results were quite sizeable. The authors are using a wedge to produce this desired lift rather than a hydrofoil at the stern. An analytical study could be carried out to determine the lift by a wedge, however,

the same wedge can be determined faster by an experimental program using wax wedges. The actual selection, therefore, of wedge dimensions was based on prior resistance tests with wedges conducted by NSRDC on 83 & 95 Ft CG patrol boats (12) and a 154 Ft PGM (13). The wedge sizes were scaled to the DD 710 and used as the first variation. Table 6 shows the dimensions for the wedge configuration selected as the best for each model after several variations of wedge slope and height at transom were tested (see appendix 4 for photographs). It is seen from the table that the wedges for models 2 and 3 were the same size. These two models had zero dead rise. The first model which needed a larger wedge had considerable deadrise at the transom. All of the wedges were made from standard household parafin and extended the full width of the transom.

TABLE 6 - WEDGES TESTED

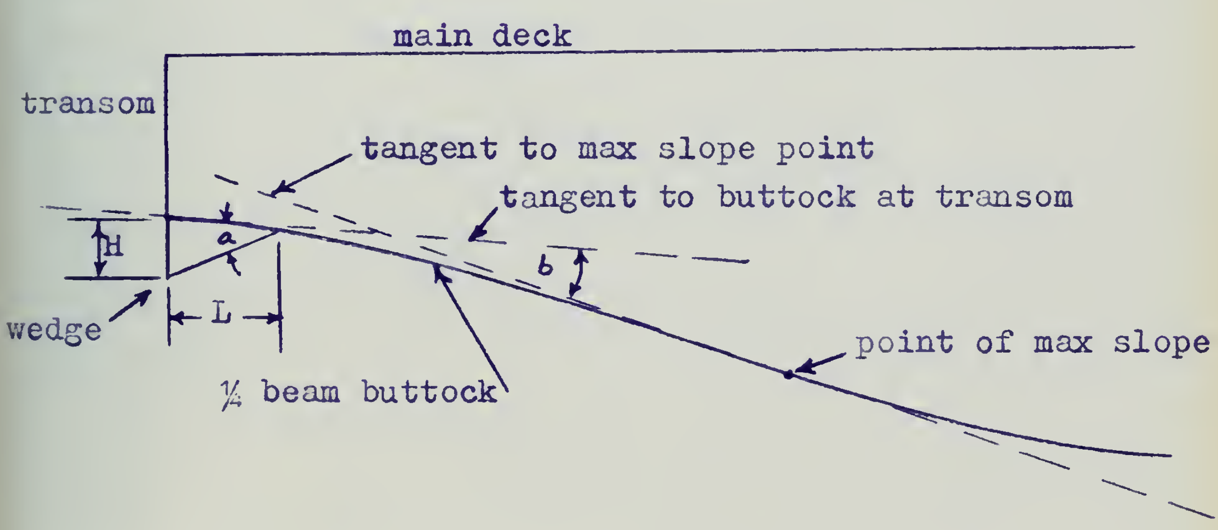
LBP_{model} = 4.49 FT LBP_{ship} = 383 FT

MODEL	WEDGE ANGLE (a)	TOTAL DEFLECTION OF WATER (a+b)	WEDGE DIMENSIONS MODEL-IN L	H	SHIP-FT L	H	
1	15.6°	19.4°	0.97	0.27	6.9	1.9	
	10.5	14.3	0.97	0.18	6.9	1.3	
	8.2	12.8	0.97	0.14	6.9	1.0	
	14.9	18.7	0.49	0.13	3.5	0.9	
	* 23.8	27.6	0.25	0.11	1.8	0.8	*
2	21.8	25.5	0.50	0.20	3.6	1.4	
	11.3	15.0	0.50	0.10	3.6	0.7	
	* 21.8	25.5	0.25	0.10	1.8	0.7	*
3	21.6	26.8	0.38	0.15	2.7	1.1	
	31.0	36.2	0.25	0.15	1.8	1.1	
	* 21.8	27.0	0.25	0.10	1.8	0.7	*

* best wedge for each set

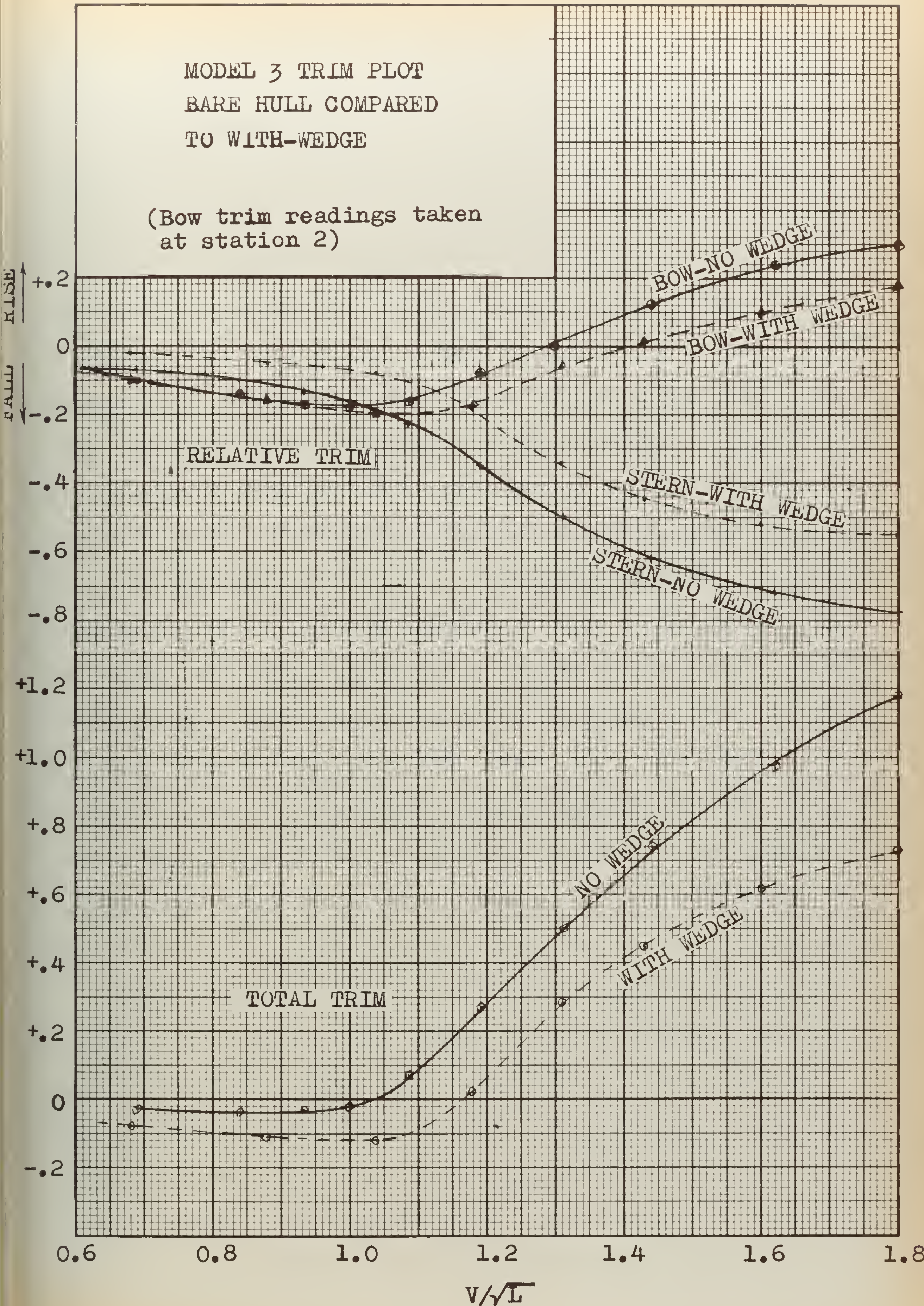
Values of b -

Model 1 b = 3.8°
2 b = 3.7°
3 b = 5.2°



SPECIAL TRIM TEST

During the tests of models 1 and 2 significant savings in resistance were achieved with a wedge over the bare hull condition at $V/\sqrt{L} = 1.2$. It was felt that the wedge changed trim, reduced "squat" which resulted in lower resistance. In order to determine the relation between wedge lift and trim, a special trim test was conducted with model 3. The test involved taking readings both bare hull and with wedge over the complete speed range. The model was then retrimmed, without wedge, to the corresponding trim with wedge at the same speed. The resistance results did not show a saving, on the contrary, they indicated a slight increase in resistance over the bare hull values. A study of the trim plots, figure 15, on the other hand, indicated that the wedge actually reduced the displacement of the model. This is explained by noting that the relative sinkage of the stern bare hull is greater than the corresponding condition for the model with a wedge. The conclusion can therefore be drawn that a wedge actually lifts the hull out of the water at the stern, thereby decreasing resistance as well as delaying squat.



MODEL 3 TRIM PLOT
BARE HULL COMPARED
TO WITH-WEDGE
(Bow trim readings taken at station 2)
RISE
FALL
+.2
0
-.2
-.4
-.6
-.8
+1.2
+1.0
+.8
+.6
+.4
+.2
0
-.2
BOW-NO WEDGE
BOW-WITH WEDGE
RELATIVE TRIM
STERN-WITH WEDGE
STERN-NO WEDGE
NO WEDGE
WITH WEDGE
TOTAL TRIM
0.6
0.8
1.0
1.2
1.4
1.6
1.8
$V/\sqrt{L}$

FIG-15

LINES AND MODEL CONSTRUCTION

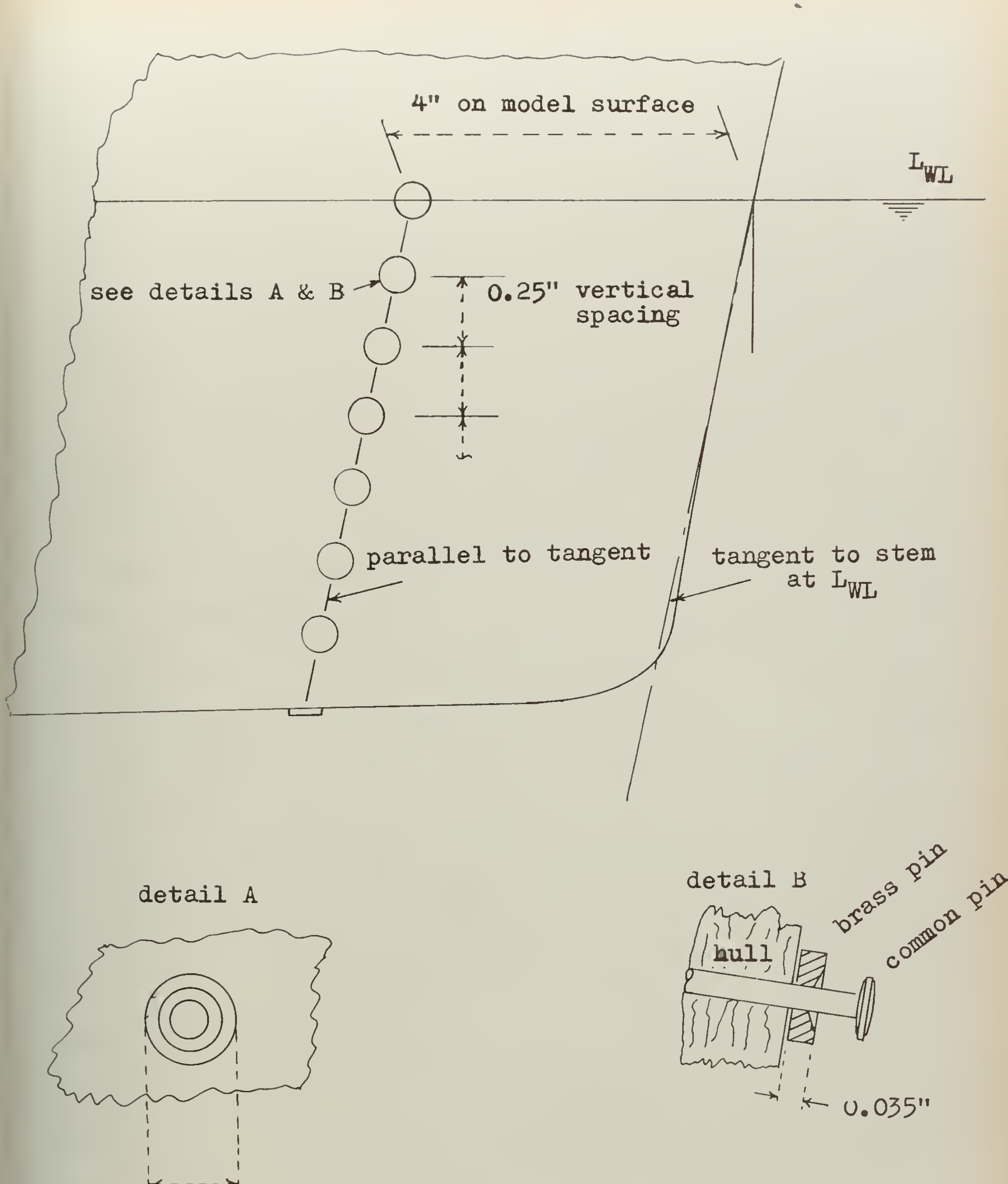
The original lines had to be developed from the available DD 710 model (see appendix 4 for photographs). The station offsets were lifted with a sliding pin offset template designed specifically for the job. The offsets were accurate to 0.005" when transferred to fiberglass drafting cloth. This accuracy was deemed desirable to reduce the magnitude of final error, as small differences in resistance output from the regression analysis equation were dependent on precise coefficients. With an established set of forebody lines it was only necessary to fair the selected afterbody variations to the maximum section. Body plans were developed from five variations of slope of keel aft corresponding to the selected afterbody parameters. One body plan was selected from the group as the most suitable shape for mounting rudders, appendages, and permitting large propellers to be installed. The final faired lines were prepared as shown in figures 11 thru 13.

The successive model modifications were accomplished at the Naval Ship Research and Development Center, Carderock (NSRDC) using the existing model and modifying its afterbody, (see appendix 4 for photographs). The variations were developed with epoxy compound called pattern putty. The substance is ideal for models in that it has no moisture-absorbing grain and is not

affected by humid or moist climatic conditions. The epoxy hardness is similar to wood so feathering was easy.

TEST PROCEDURE AND EXPANSION METHODS

All models were tested in the Webb Towing Tank in fresh water at 80± 0.5°F. standard towing procedures of that tank were followed. Stimulation was achieved by three means: first, the elevated water temperature; second, by a 1½ minute interval between resistance runs, in order to maintain the turbulence level in the tank; and finally, by a row of 1/8" dia. x .035" spaced ¼" apart pin stimulators located 4 inches aft of the stem, figure 16. The basis for selection of pin type stimulators is documented in C. Ridgely-Nevitt's 1963 SNAME paper on "The Development of Parent Hulls for a High Displacement-Length Series of Trawler Forms" (14). The speed range covered by the tests was from $V/\sqrt{L} = 0.7$ to 2.0. Blockage was not considered a problem as the model was small with relatively low wave making resistance. With a rectangular tank 10 ft wide and 5 ft deep, the blockage values ranged from 0.11 - 0.13 per cent. The authors expanded the model data to 59°F SW and C using the International Towing Tank Conference Correlation Line (15) with a correlation allowance of 0.0004. This is also standard Webb Towing Tank procedure.



PIN STIMULATORS

FIG-16

RESULTS

Resistance plots are presented herein on a relative resistance scale because security regulations require absolute values to be classified for combatant naval ships. Speed-length ratio is used as the base in order to compare the various displacements of each model, as they are all of the same length.

Figures 17 thru 19 show the resistance curves as determined experimentally in the Webb Towing Tank and analytically using the DTMB regression equation. The experimental data above $V/\sqrt{L} = 1.2$ is relatively uniform. Humps appear at the lower speeds due to wave interference. This is especially noticeable for the +10% displacement of model 3 at $V/\sqrt{L} = 0.88$ (fig. 19). The regression equation output for model 1, figure 17, for all displacements is uniform and free of oscillation, as it should be, since the coefficients fall in the center of the input data for the equation (see figures 6 thru 10). This is definitely not true for model 2, figure 18. The oscillations and lack of uniformity between displacements is not unexpected, however, as the transom width ratio is well outside the equations limits (see figures 6, 8, 9 and 10). Model 3, figure 19, being on the outer limit of input data, with respect to its transom width ratio, (again see figures 6, 8, 9 and 10) shows some inconsistency especially in the case

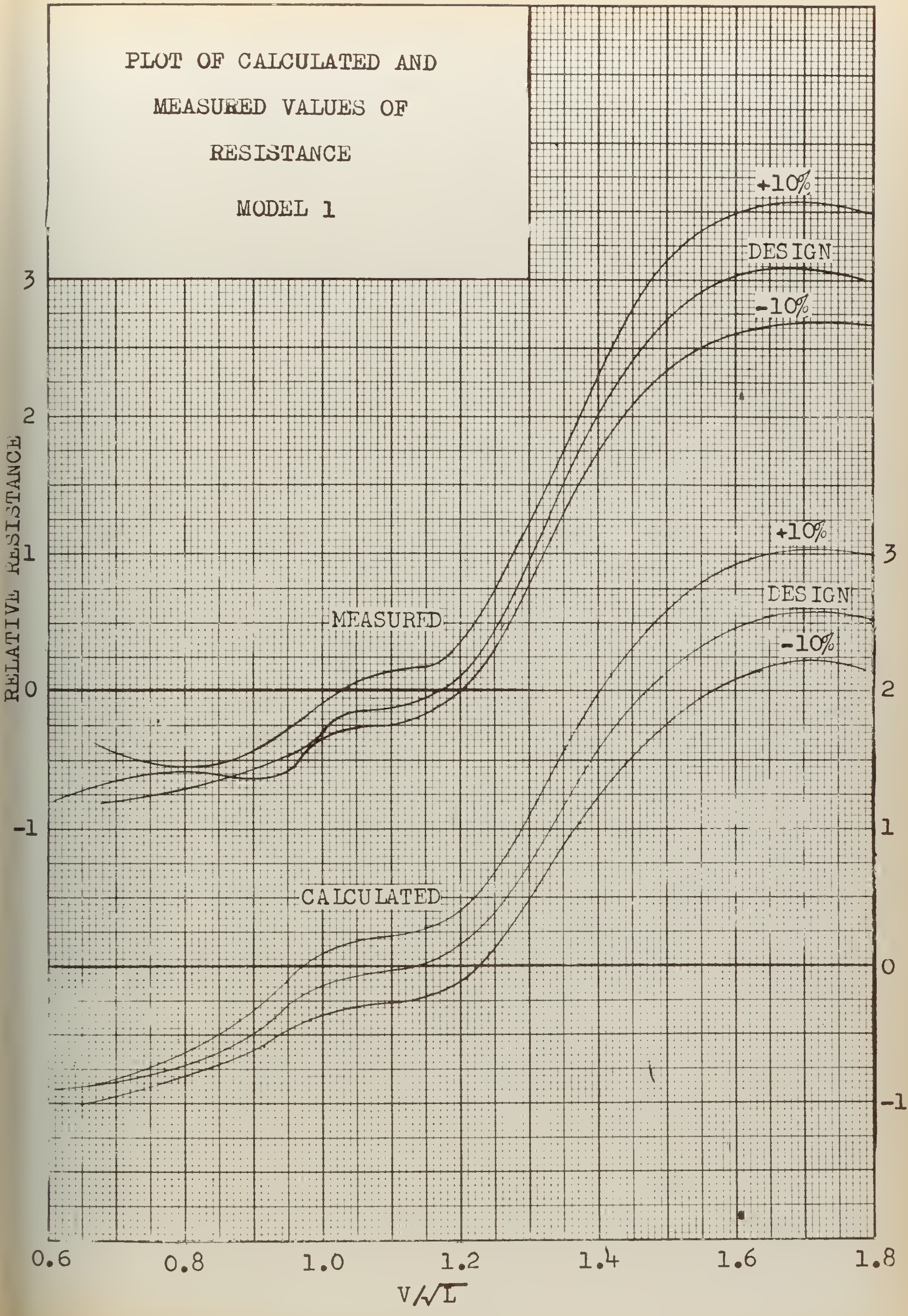

PLOT OF CALCULATED AND
MEASURED VALUES OF
RESISTANCE
MODEL 1
RELATIVE RESISTANCE
+10%
DESIGN
-10%
MEASURED
CALCULATED
3
2
1
0
-1
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V/√L

FIG-17

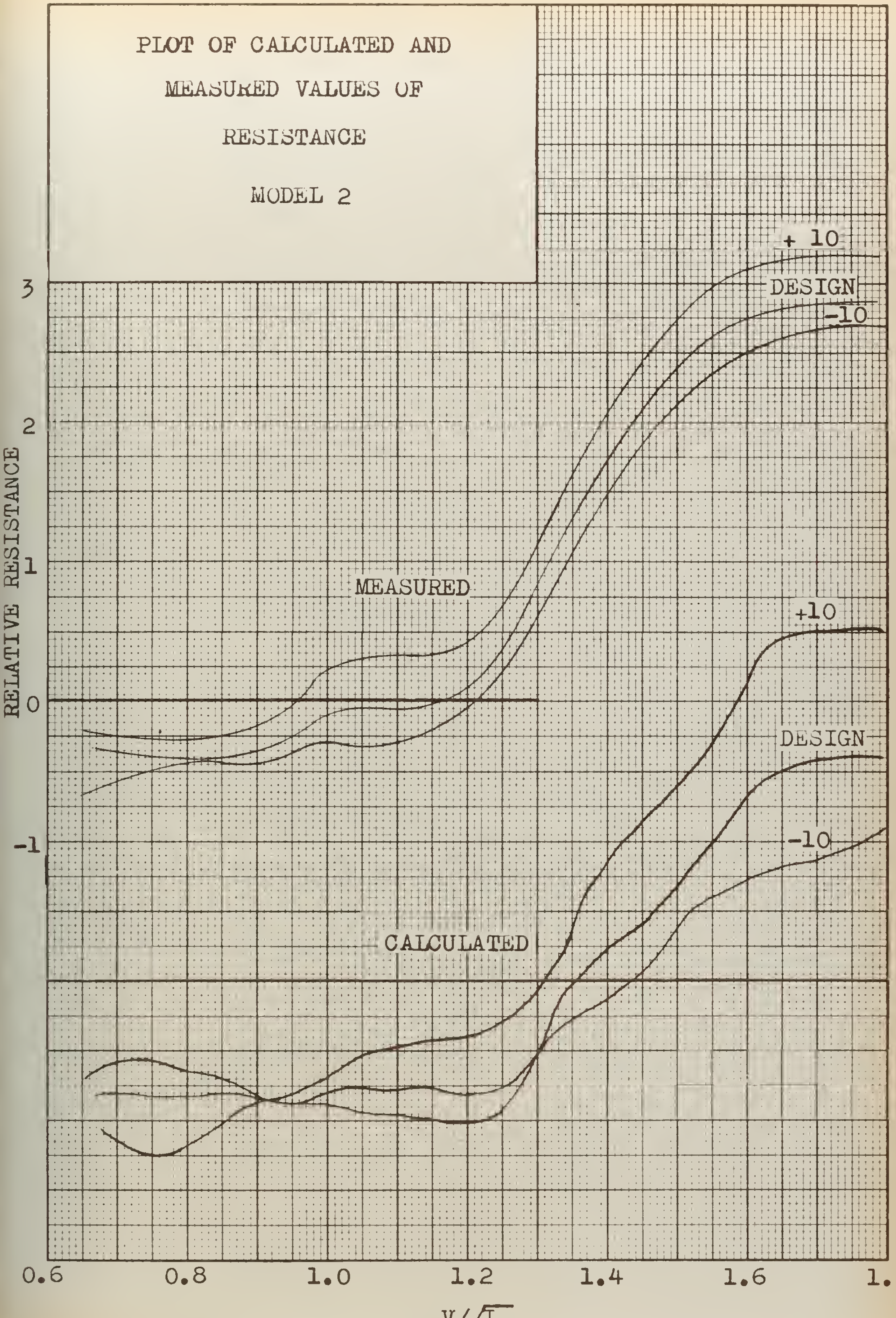

PLOT OF CALCULATED AND
MEASURED VALUES OF
RESISTANCE
MODEL 2
RELATIVE RESISTANCE
3
2
1
0
-1
MEASURED
+ 10
DESIGN
-10
CALCULATED
+10
DESIGN
-10
3
2
1
0
-1
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V/√L

FIG-18

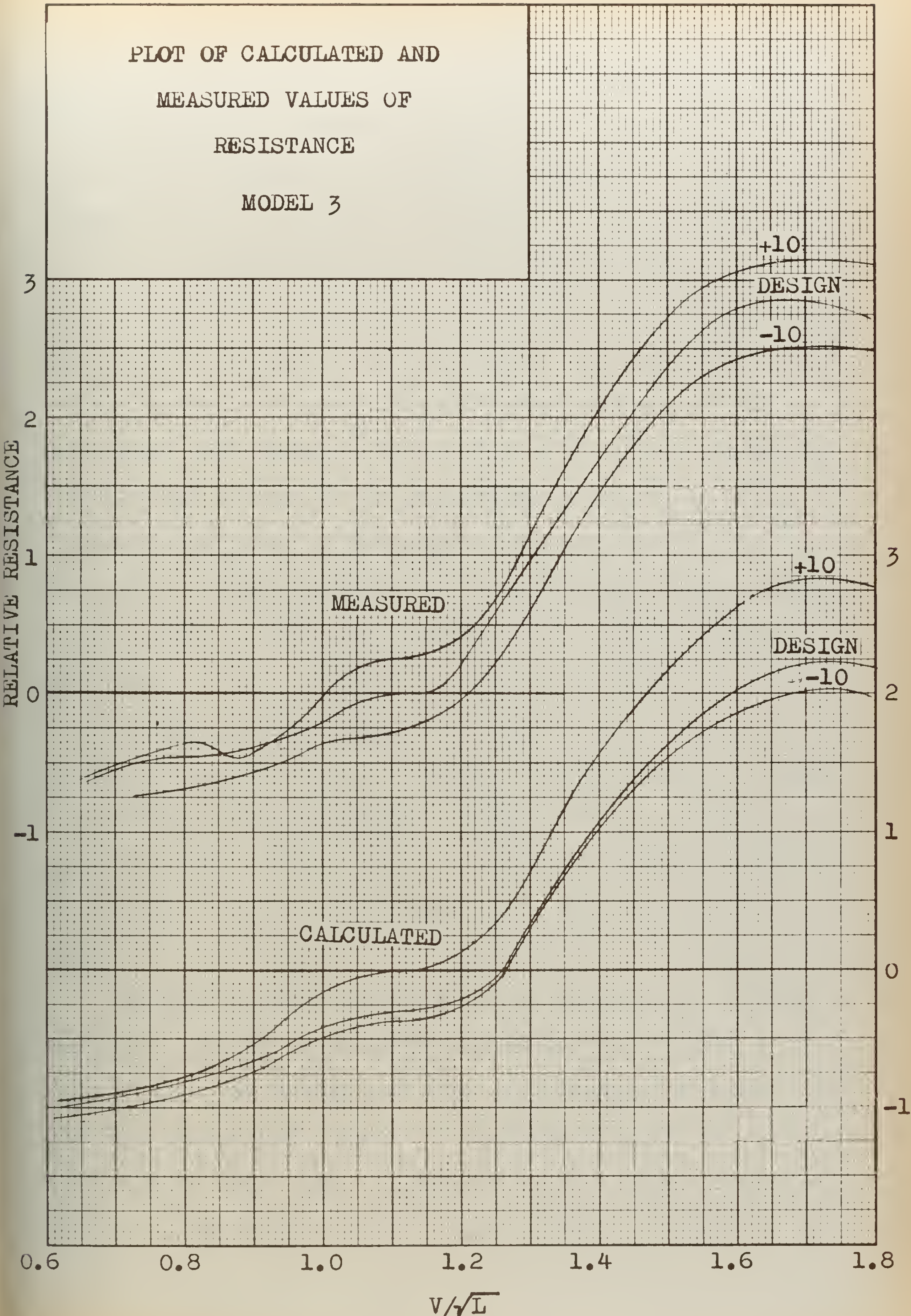

PLOT OF CALCULATED AND
MEASURED VALUES OF
RESISTANCE
MODEL 3
RELATIVE RESISTANCE
3
2
1
0
-1
+10
DESIGN
-10
MEASURED
+10
DESIGN
-10
CALCULATED
3
2
1
0
-1
0.6
0.8
1.0
1.2
1.4
1.6
1.8
$V/\sqrt{L}$

FIG-19

of the design and -10% displacements. The previously presented experimental resistance curves are replotted in figures 20 thru 22 against their respective regression resistance curves for comparison. Figure 20 shows a poor fit at all displacements for model 1 at high speeds with a maximum error of approximately 7%. Model 2, figure 21, also shows a poor fit between measured and calculated resistance. In addition, there are pronounced oscillations in all of the regression plots. Model 3, figure 22, indicates the character of the calculated resistance as being similar to that measured, the curves, however, are displaced vertically with a maximum error of about 10%. It is significant to note that for all models the experimental resistance was higher than that predicted by the regression analysis. As far as these tests are concerned the regression analysis did not predict the resistance of the models. However, it did indicate the correct trend in resistance for a modification of T_W/B_X.

Figures 23 thru 25 compare the experimental resistances for each constant-displacement group. Model 2 ($T_W/B_X = 1.00$) at design and +10% displacement crosses over the parent hull (model 1) resistance curve at $V/\sqrt{L} \cong 1.20$ while the crossover for the shallow depth transom (-10% displacement) is much earlier, $V/\sqrt{L} \cong 1.0$

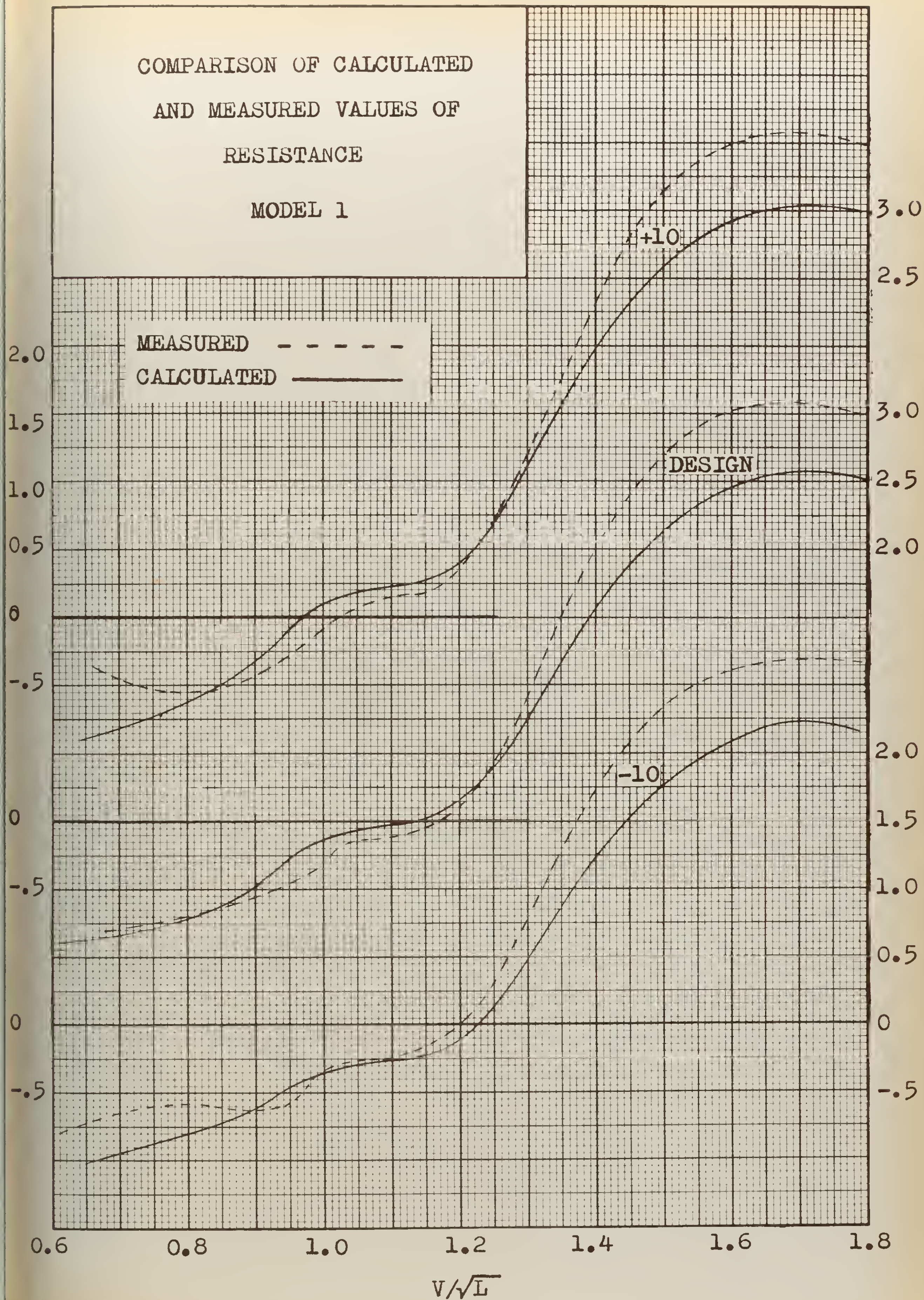

COMPARISON OF CALCULATED AND MEASURED VALUES OF RESISTANCE
MODEL 1
MEASURED
CALCULATED
+10
DESIGN
-10
2.0
1.5
1.0
0.5
0
-.5
0
-.5
0
-.5
3.0
2.5
3.0
2.5
2.0
2.0
1.5
1.0
0.5
0
-.5
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V/√L

FIG-20

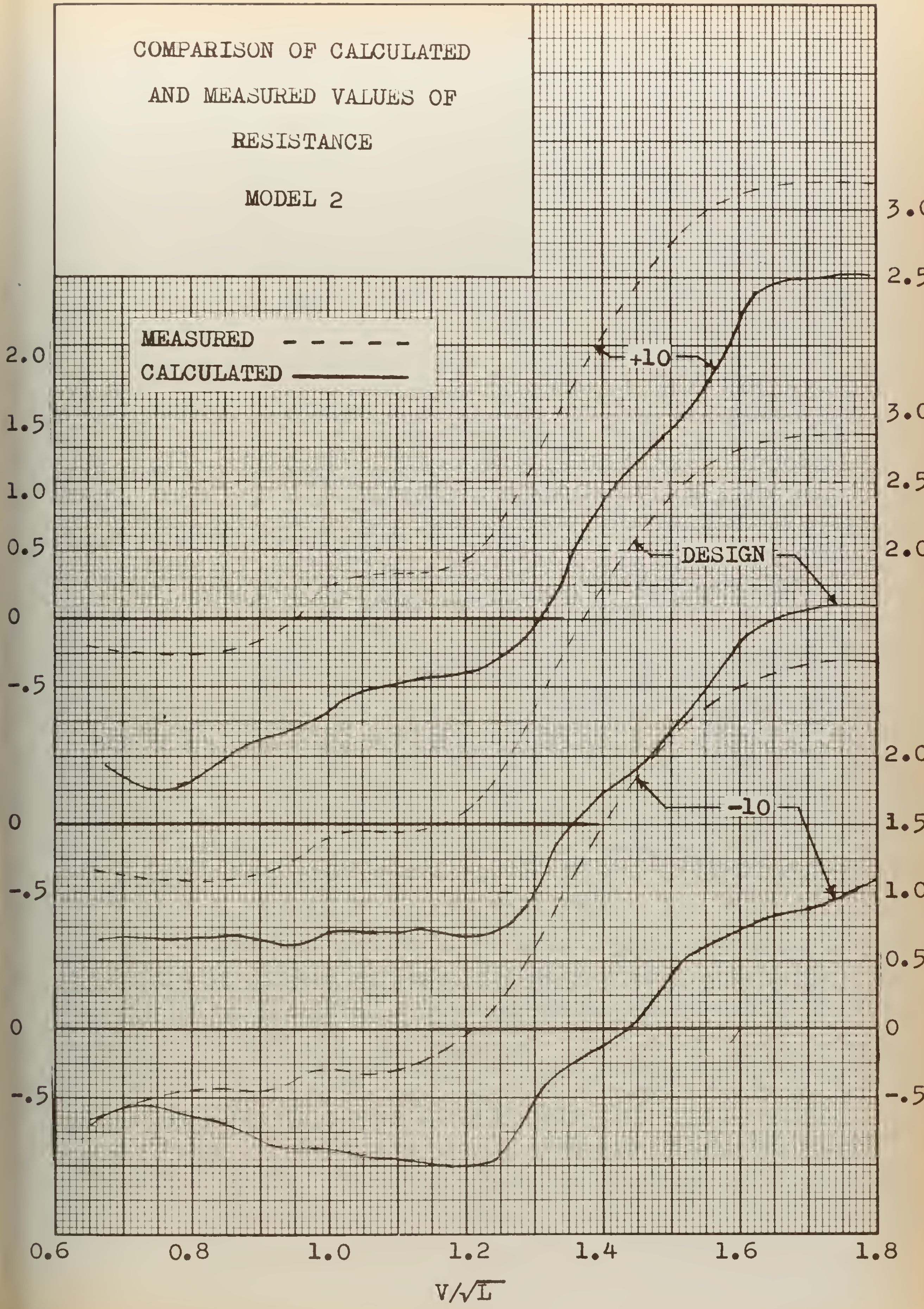

COMPARISON OF CALCULATED
AND MEASURED VALUES OF
RESISTANCE
MODEL 2
MEASURED - - - - - -
CALCULATED
+10
DESIGN
-10
2.0
1.5
1.0
0.5
0
-.5
0
-.5
0
-.5
3.0
2.5
3.0
2.5
2.0
2.0
1.5
1.0
0.5
0
-.5
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V/√L

FIG-21

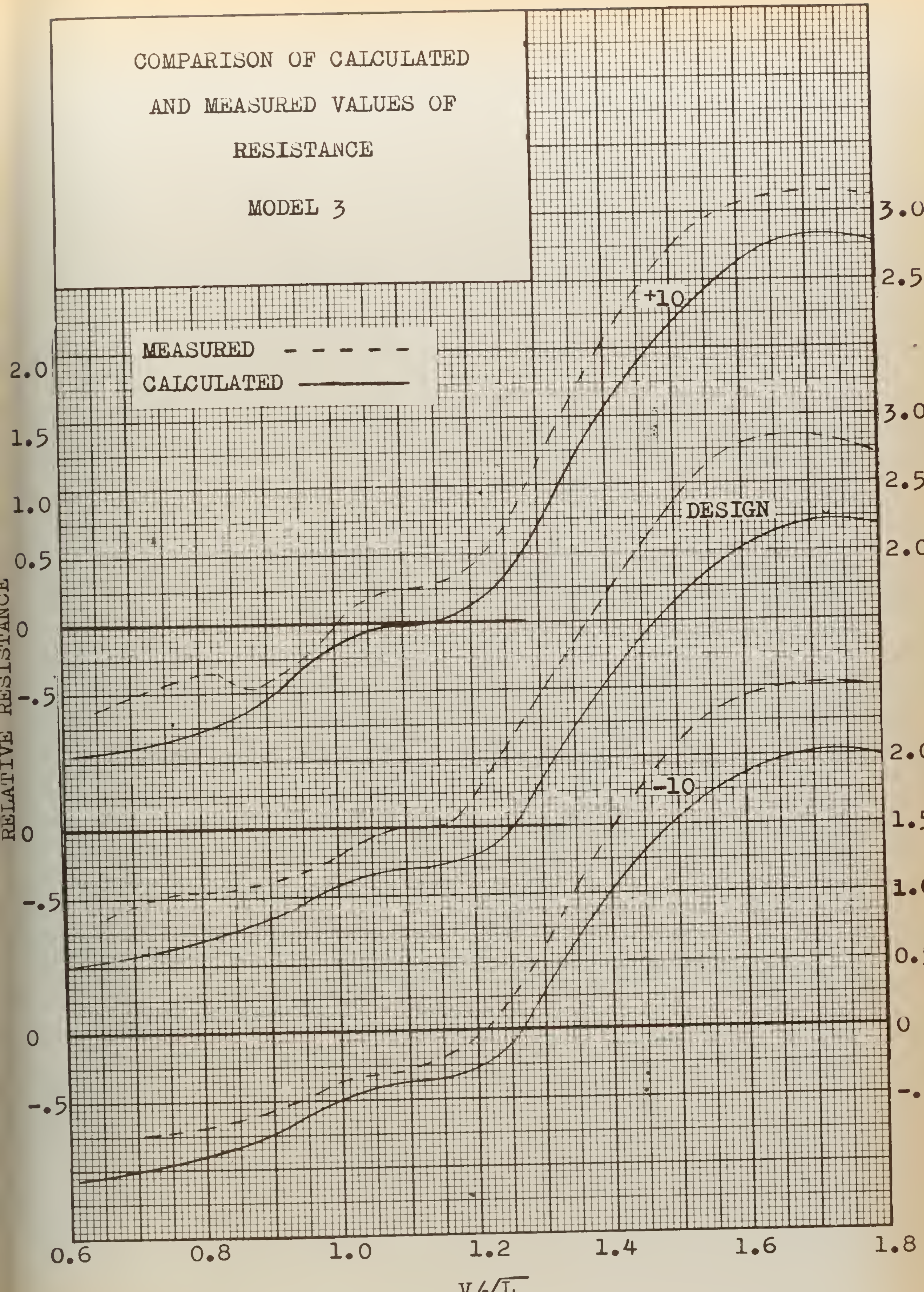

COMPARISON OF CALCULATED AND MEASURED VALUES OF RESISTANCE
MODEL 3
MEASURED - - - - -
CALCULATED ———
+10
DESIGN
-10
RELATIVE RESISTANCE
2.0
1.5
1.0
0.5
0
-.5
0
-.5
0
-.5
3.0
2.5
3.0
2.5
2.0
2.0
1.5
1.0
0.5
0
-.5
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V/√L

FIG-22

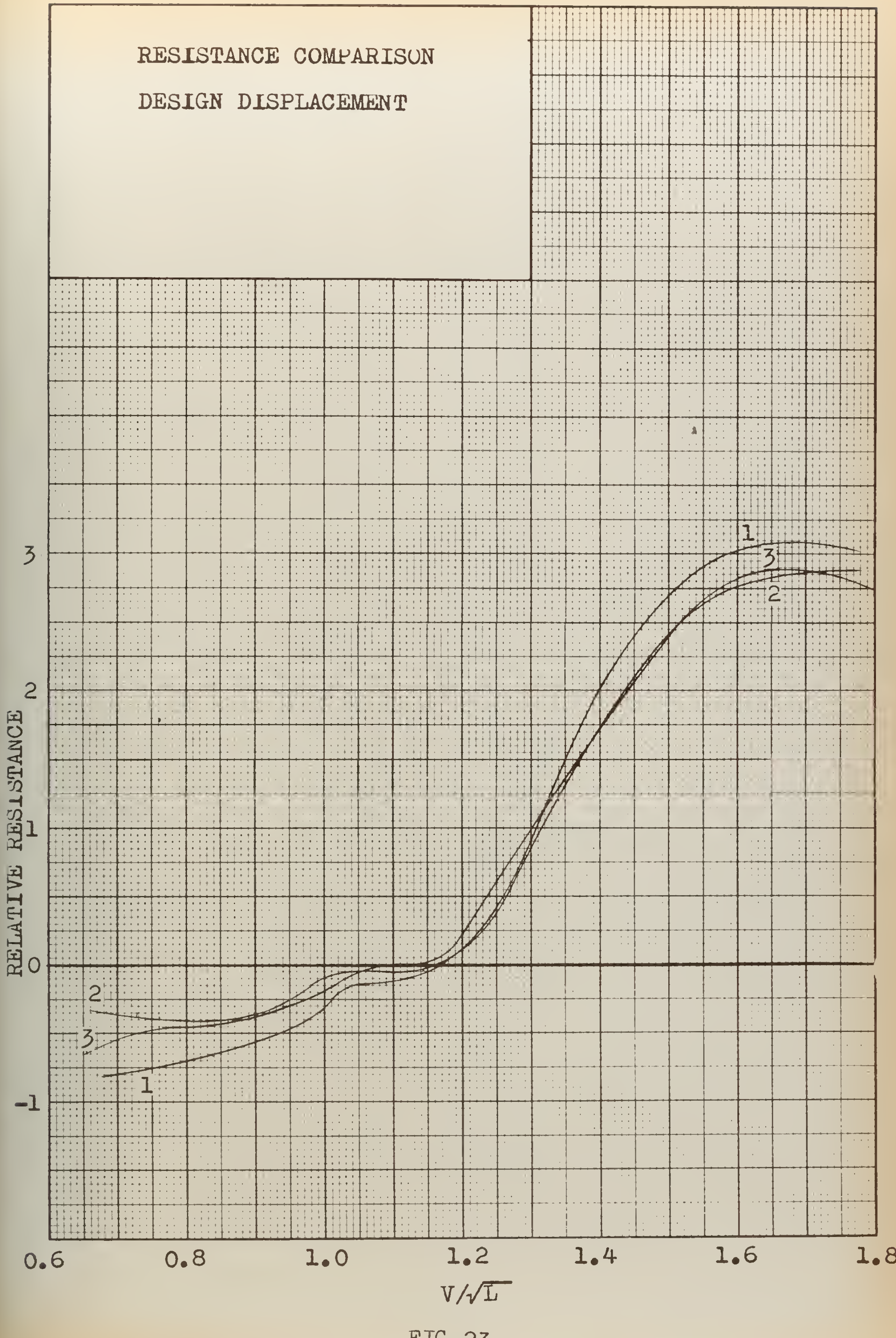

RESISTANCE COMPARISON
DESIGN DISPLACEMENT
RELATIVE RESISTANCE
3
2
1
0
-1
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V/√L
1
2
3

FIG-23

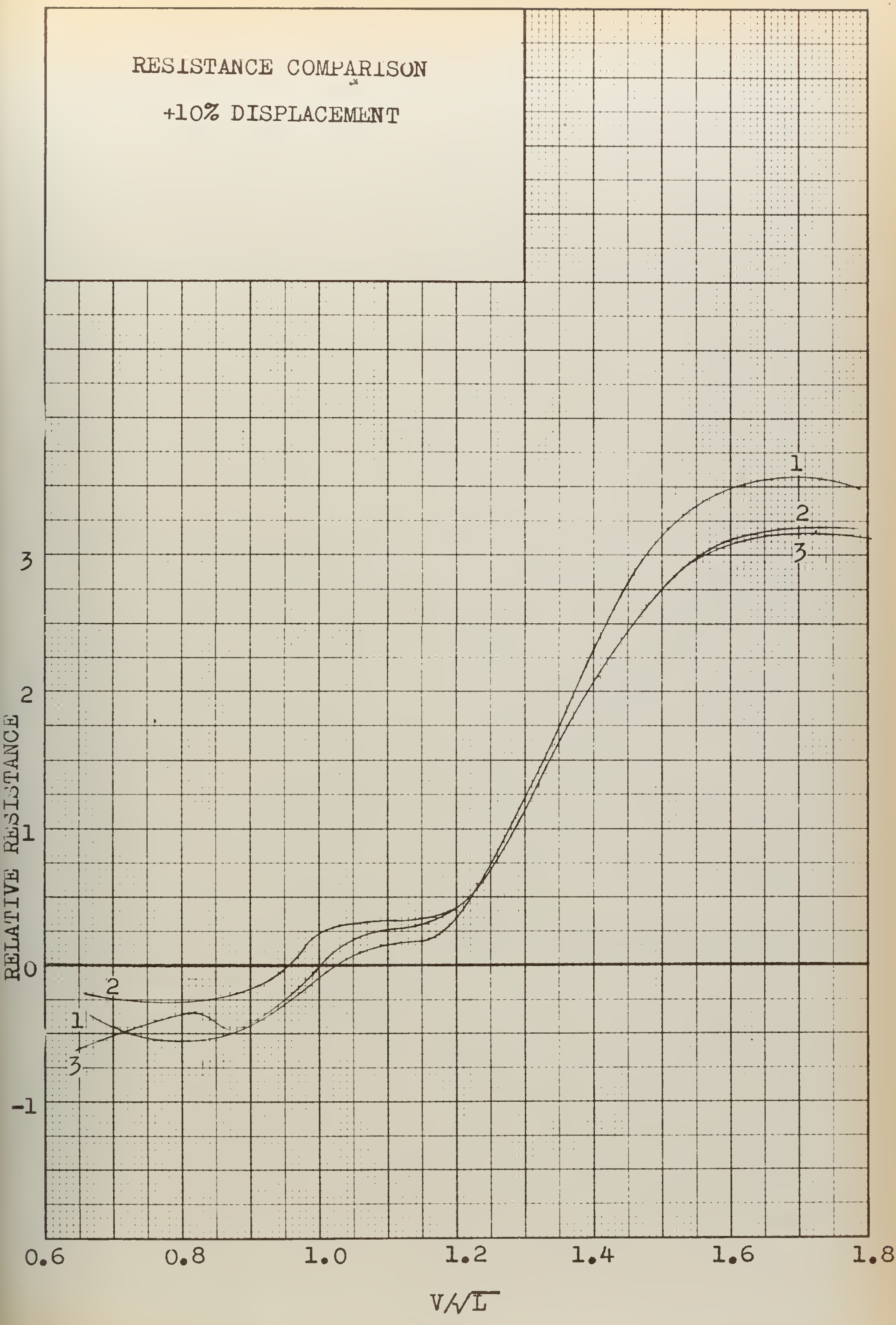

RESISTANCE COMPARISON
+10% DISPLACEMENT
RELATIVE RESISTANCE
3
2
1
0
-1
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V/√L
1
2
3

FIG-24

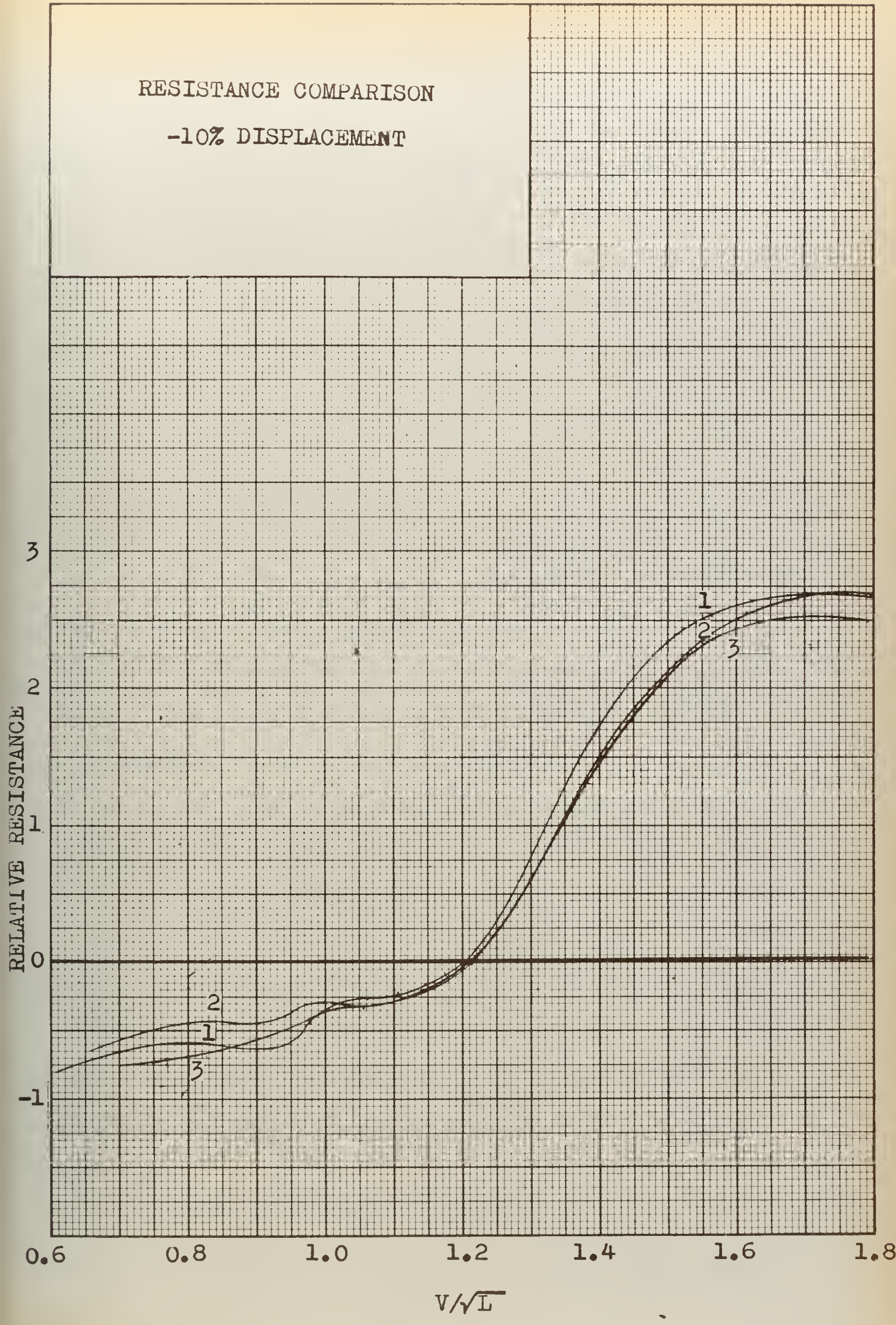

RESISTANCE COMPARISON
-10% DISPLACEMENT
RELATIVE RESISTANCE
3
2
1
0
-1
0.6
0.8
1.0
1.2
1.4
1.6
1.8
1
2
3
V/√L

FIG-25

As was predicted during the design stage, model 3 (T_W/B_X= 0.750) follows the pattern of model 2 in the higher speed ranges. The crossover of model 3 with respect to model 1 at design and +10% displacement again occurs at $V/\sqrt{L} \cong 1.2$. As seen with model 2, the shallow-depth transom version of model 3 also displays better resistance characteristics at an earlier speed.

The resistance comparisons "Bare Hull vs With Wedge" of the three models at their design displacements are plotted in figures 26 thru 29. The curves show that by adding a wedge (wedge sloped 22°, length 1.8', height 0.7' full size) designed for high-speed saving with minimum low-speed drag, significant savings can be realized. It is interesting to note that the crossover points of the wedge and bare hull with resistance curves are a function of the models' transom width ratio. Model 2 with the widest wedge (T_W/B_X= 1.00) is the first to show a resistance saving over it's bare hull, $V/\sqrt{L} \cong 0.9$. Model 3 (T_W/B_X= 0.75) follows at $V/\sqrt{L} \cong 1.1$ and model 1 (T_W/B_X=0.558) at $V/\sqrt{L} \cong 1.3$. It also should be noted that both models 2 and 3 bare hull have essentially the same resistance throughout the speed range as model 1 with its wedge, figure 29.

A comparison of the resistance curves for the three models with wedges is shown in figure 30. Model 2

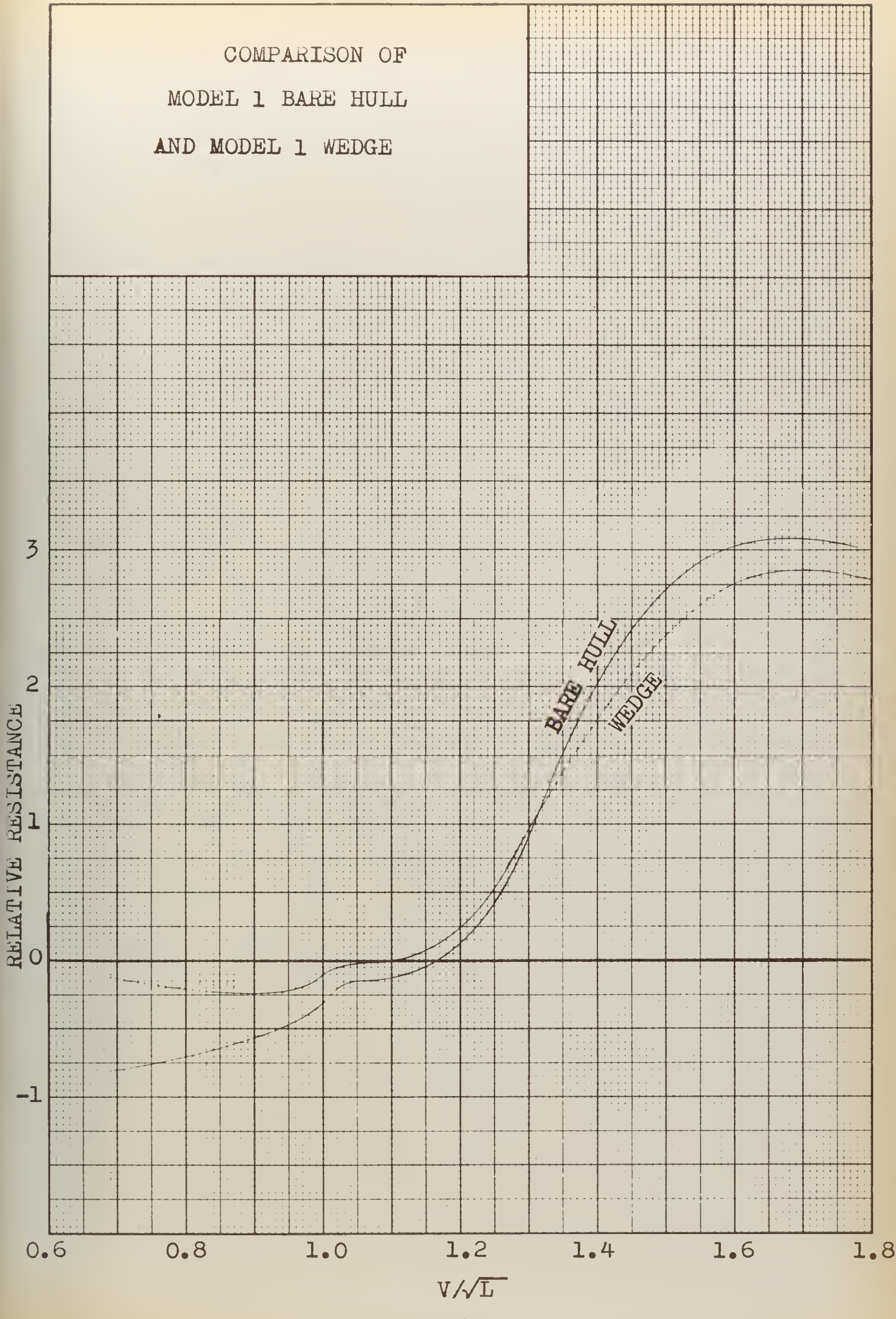

COMPARISON OF
MODEL 1 BARE HULL
AND MODEL 1 WEDGE
RELATIVE RESISTANCE
3
2
1
0
-1
BARE HULL
WEDGE
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V/√L

FIG-26

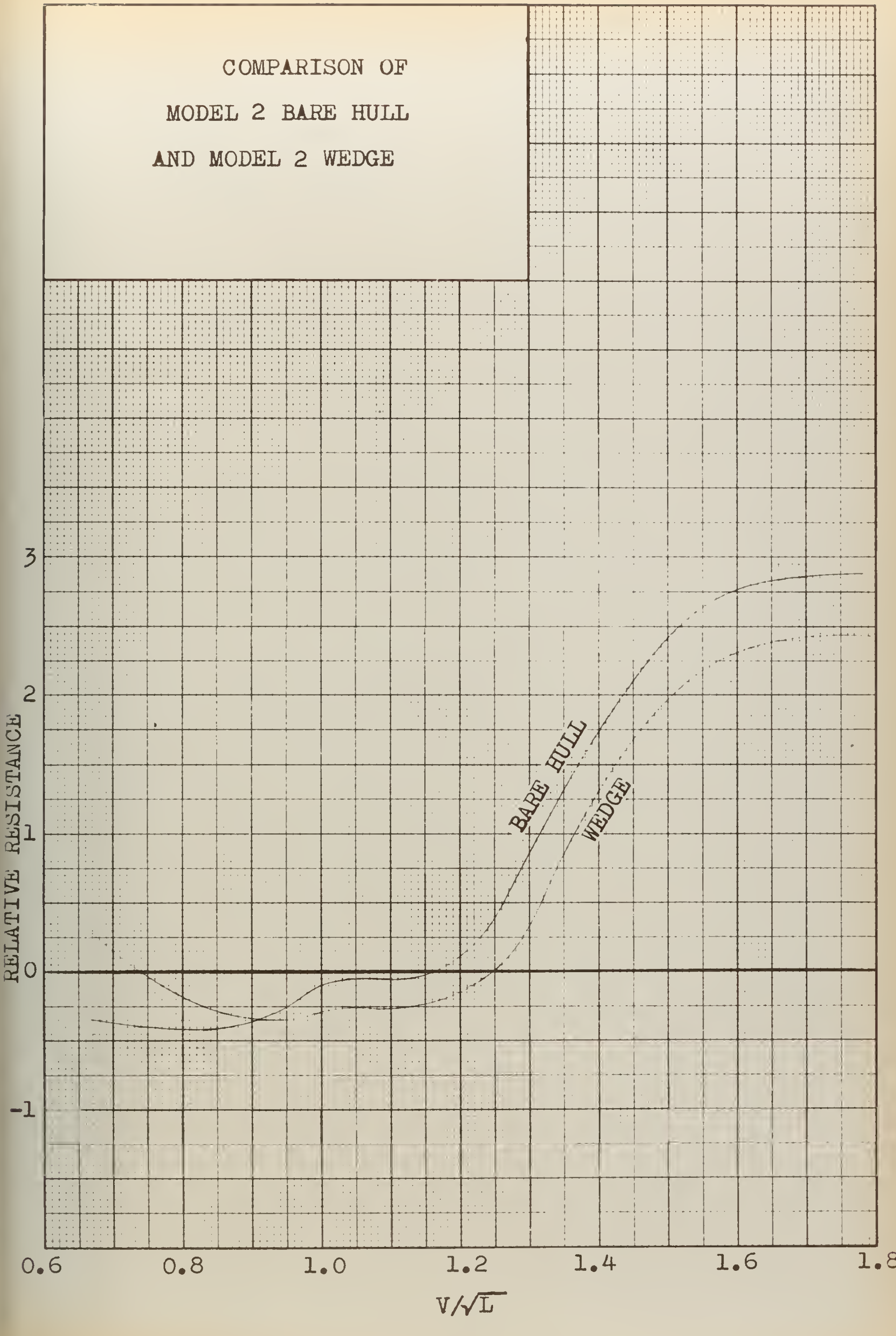
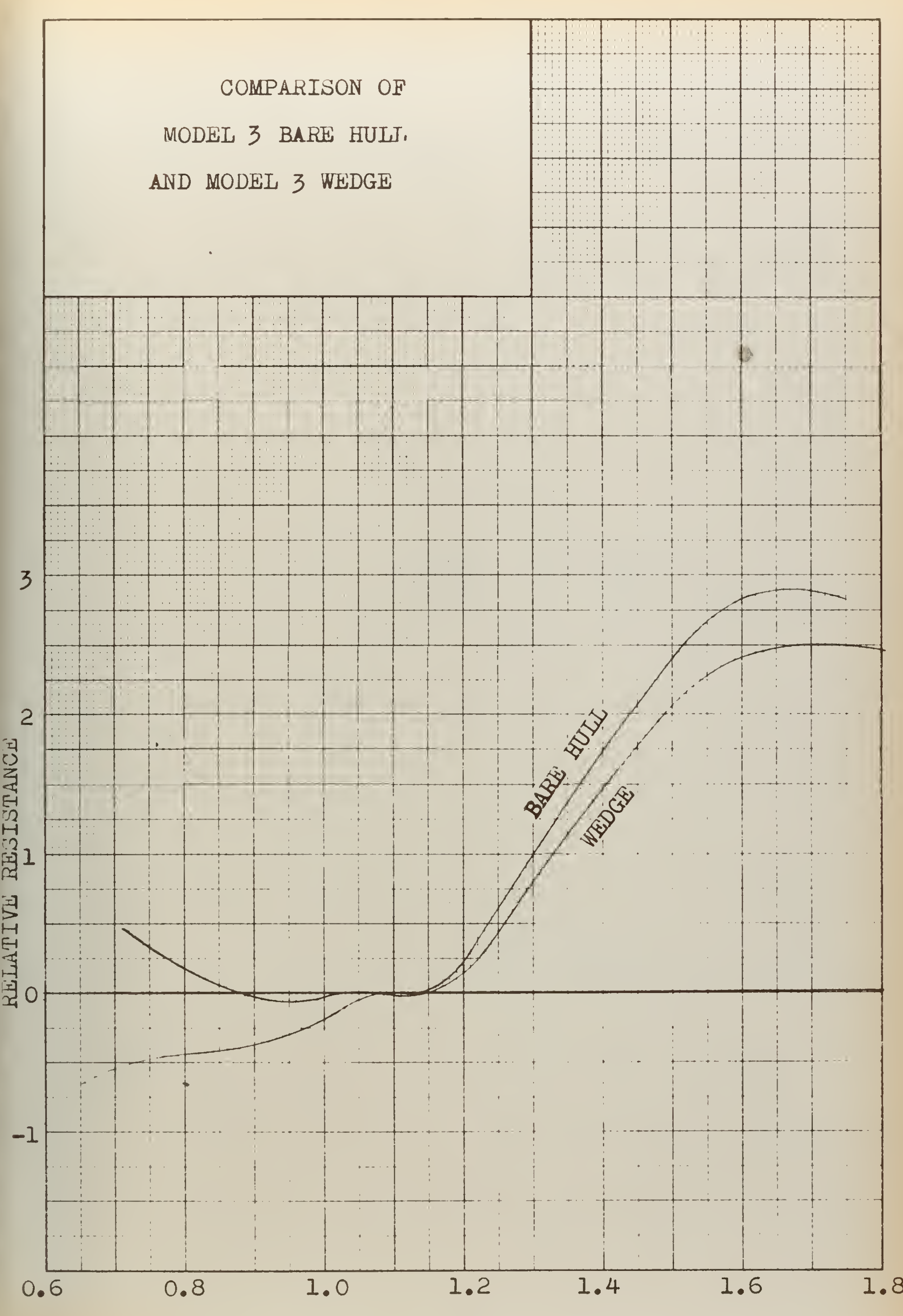

COMPARISON OF
MODEL 2 BARE HULL
AND MODEL 2 WEDGE
RELATIVE RESISTANCE
3
2
1
0
-1
BARE HULL
WEDGE
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V/√L

FIG-27



COMPARISON OF
MODEL 3 BARE HULL
AND MODEL 3 WEDGE
BARE HULL
WEDGE
RELATIVE RESISTANCE
3
2
1
0
-1
0.6
0.8
1.0
1.2
1.4
1.6
1.8
$V/\sqrt{L}$

FIG-28

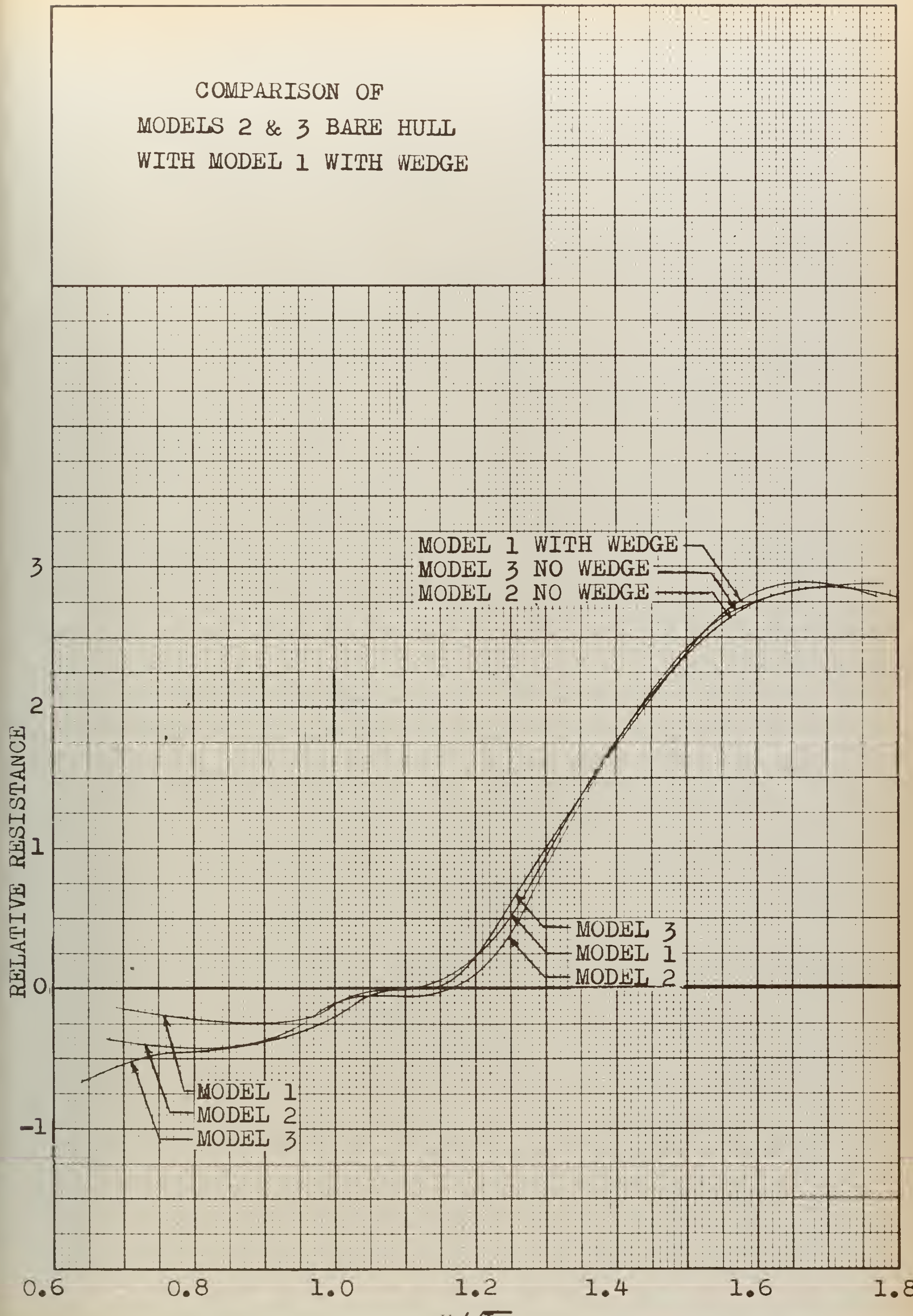

COMPARISON OF
MODELS 2 & 3 BARE HULL
WITH MODEL 1 WITH WEDGE
MODEL 1 WITH WEDGE
MODEL 3 NO WEDGE
MODEL 2 NO WEDGE
MODEL 3
MODEL 1
MODEL 2
MODEL 1
MODEL 2
MODEL 3
RELATIVE RESISTANCE
3
2
1
0
-1
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V/√L

FIG-29

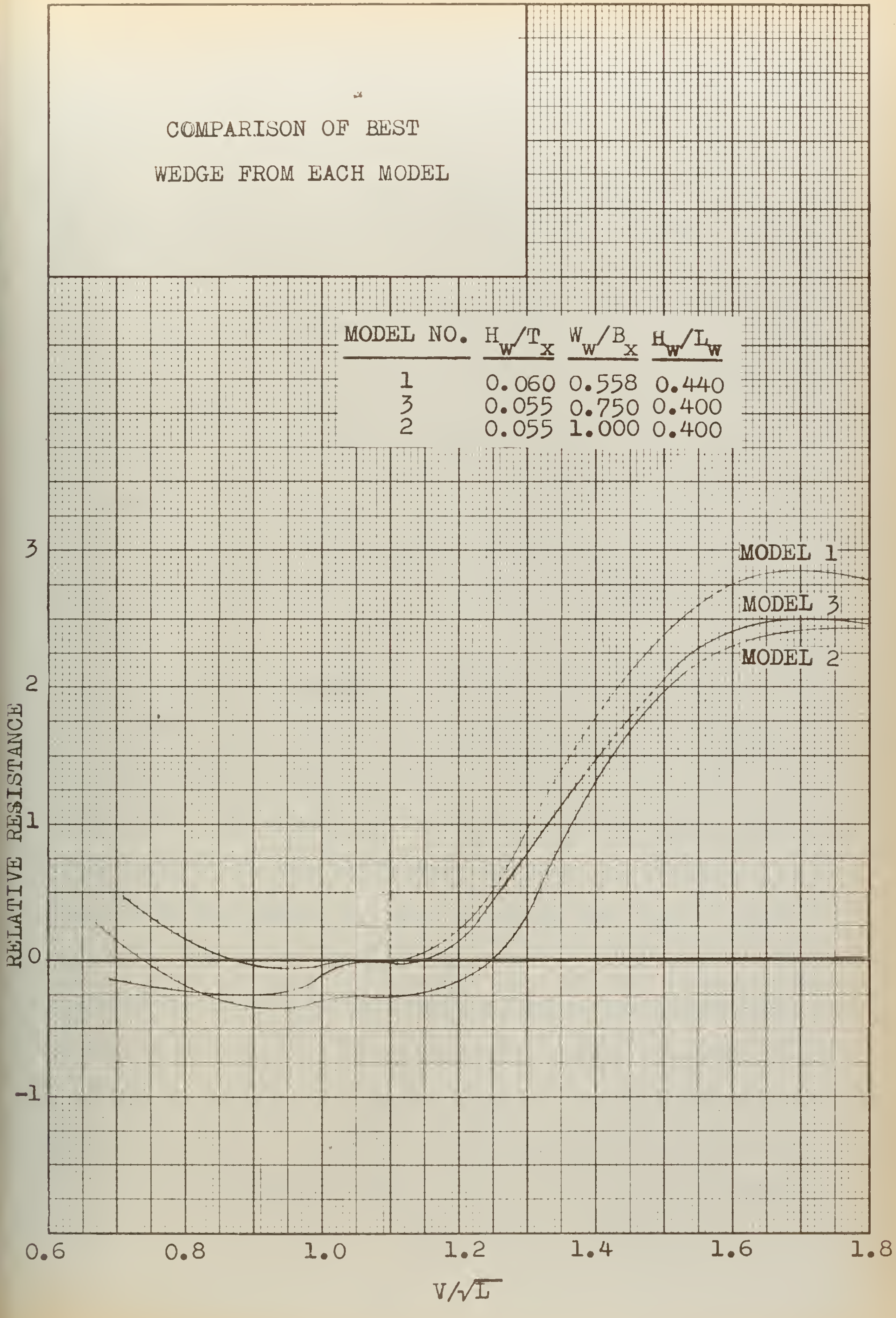

COMPARISON OF BEST
WEDGE FROM EACH MODEL
MODEL NO. H_w/T_x W_w/B_x H_w/L_w
1 0.060 0.558 0.440
3 0.055 0.750 0.400
2 0.055 1.000 0.400
MODEL 1
MODEL 3
MODEL 2
RELATIVE RESISTANCE
3
2
1
0
-1
0.6
0.8
1.0
1.2
1.4
1.6
1.8
$V/\sqrt{L}$

FIG-30

with the widest transom and, therefore, the greatest wedge lifting area indicates significant saving in the important middle speed range ($V/\sqrt{L} \geqq 0.8$) as well as the high speed range.

Figures 31 and 32 show the savings of each model as compared to the parent, model 1, at each displacement. The wedge for each model is plotted to indicate the significant saving at high speeds and the increase in resistance at low speeds. Figure 33 shows model 2 compared to model 3 which indicates similar resistance trends of the two models above $V/\sqrt{L} = 1.4$ as mentioned earlier.

A series of comparison curves, figure 34, were calculated and plotted using the reanalysis of the Taylor Standard Series by Gertler (16). By using the same forebody for all models the character of the curves is representative of the difference between the various sterns with the Taylor cruiser stern as the base. The results of the plots indicate that model 3 at -10% displacement to be approximately a 6½% better stern than the parent and almost 27% better than model 2's +10% displacement in the low speed range. In the middle speed range ($V/\sqrt{L} = 0.95$ to 1.2) the parent-hull stern at design displacement shows moderate savings over the remainder of the models. Above $V/\sqrt{L} = 1.2$ the full

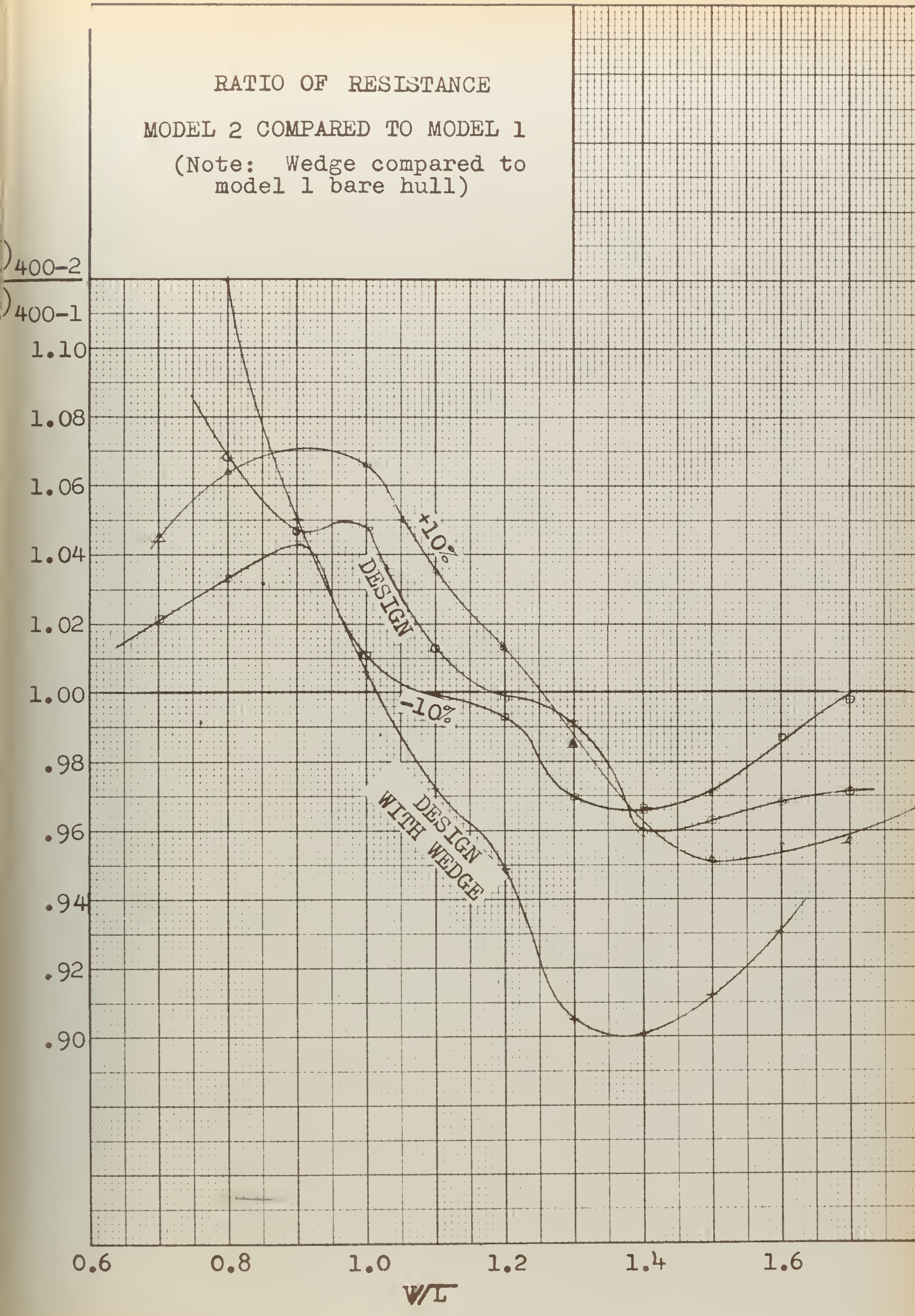

RATIO OF RESISTANCE
MODEL 2 COMPARED TO MODEL 1
(Note: Wedge compared to model 1 bare hull)
)400-2
)400-1
1.10
1.08
1.06
1.04
1.02
1.00
.98
.96
.94
.92
.90
+10%
DESIGN
-10%
DESIGN WITH WEDGE
0.6
0.8
1.0
1.2
1.4
1.6
V/L

FIG-31

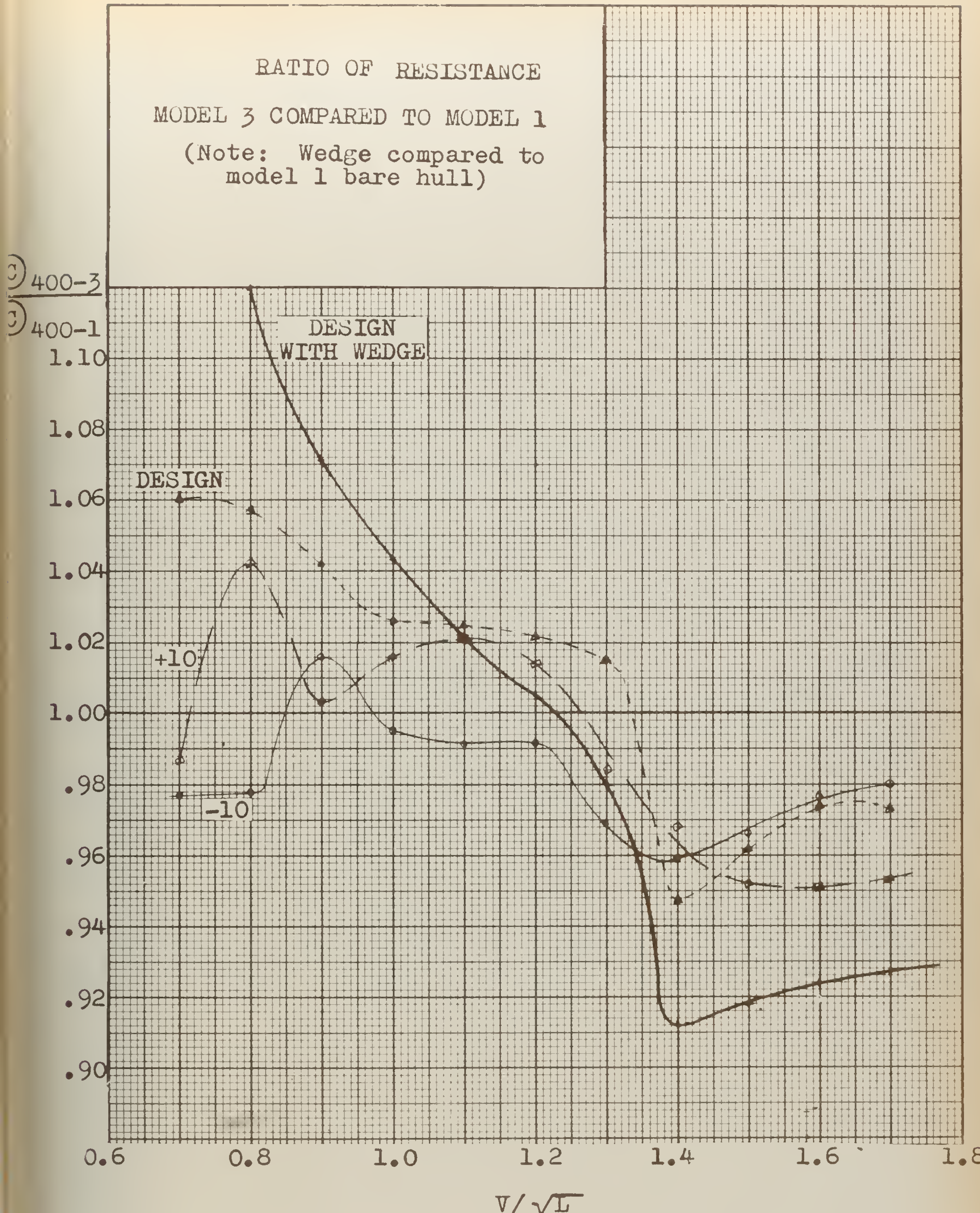
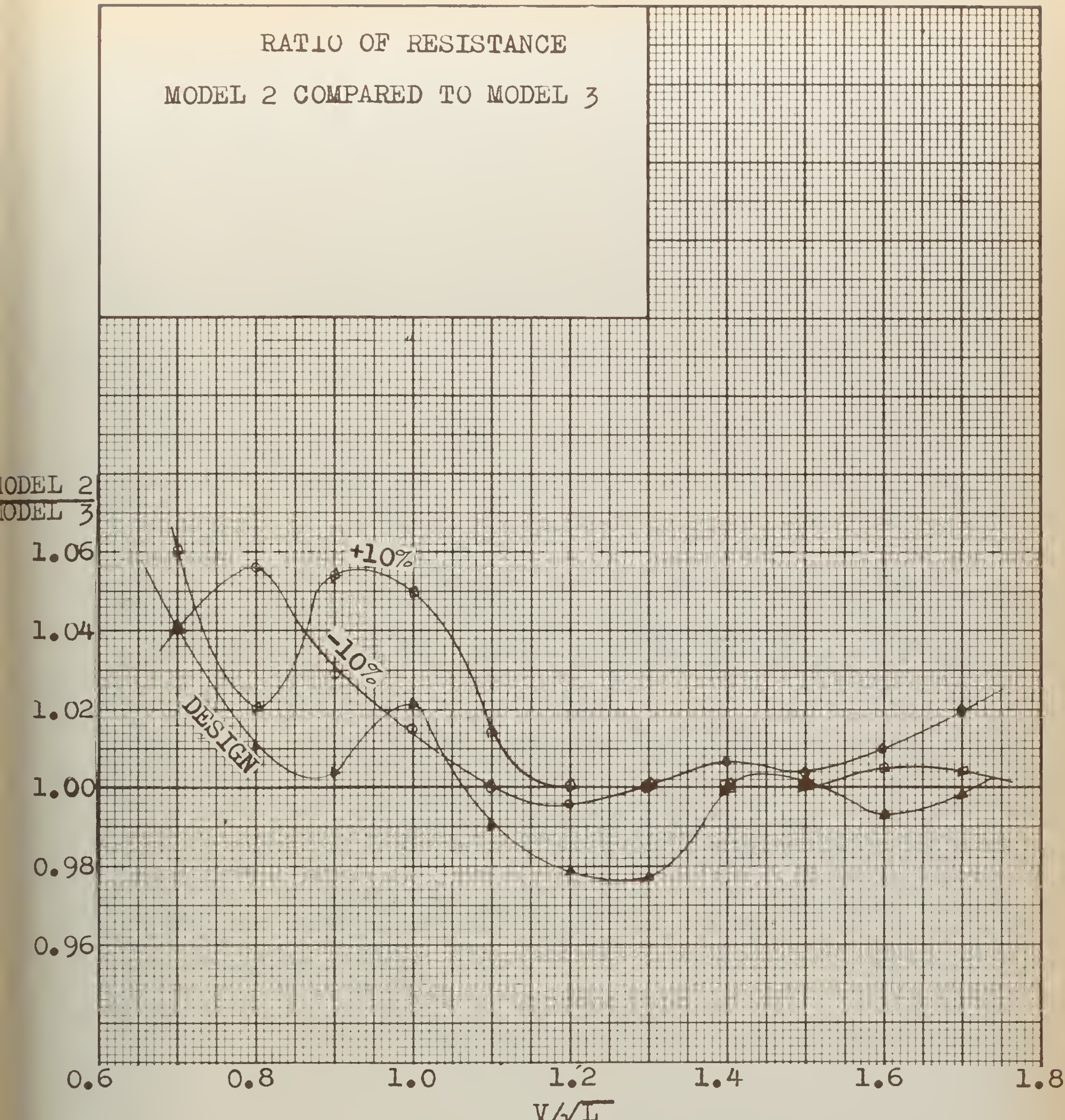
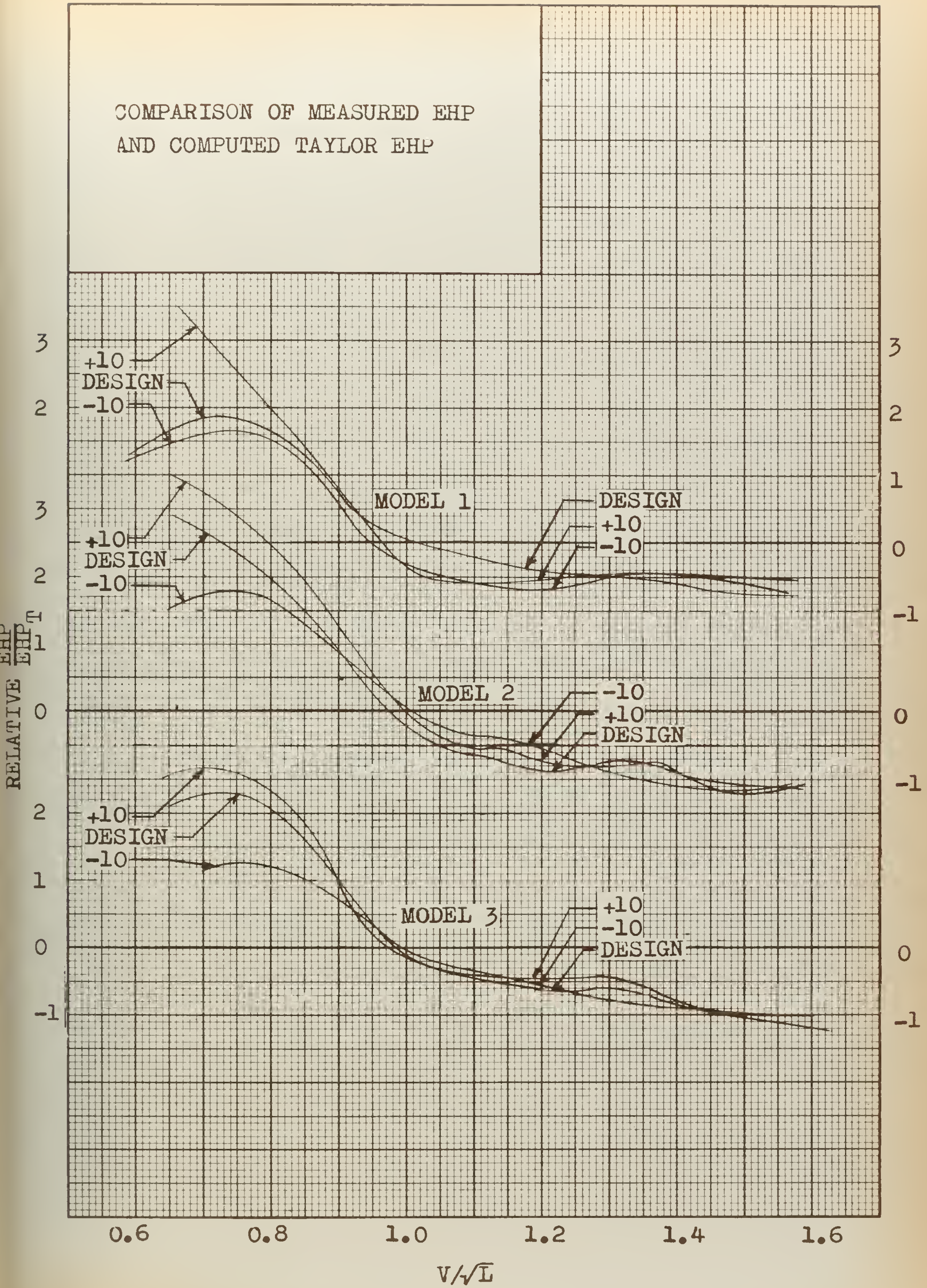

RATIO OF RESISTANCE
MODEL 3 COMPARED TO MODEL 1
(Note: Wedge compared to model 1 bare hull)
DESIGN WITH WEDGE
DESIGN
+10
-10
1.10
1.08
1.06
1.04
1.02
1.00
.98
.96
.94
.92
.90
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V/√L

FIG-32



RATIO OF RESISTANCE
MODEL 2 COMPARED TO MODEL 3
MODEL 2 / MODEL 3
1.06
1.04
1.02
1.00
0.98
0.96
+10%
-10%
DESIGN
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V/√L

FIG-33

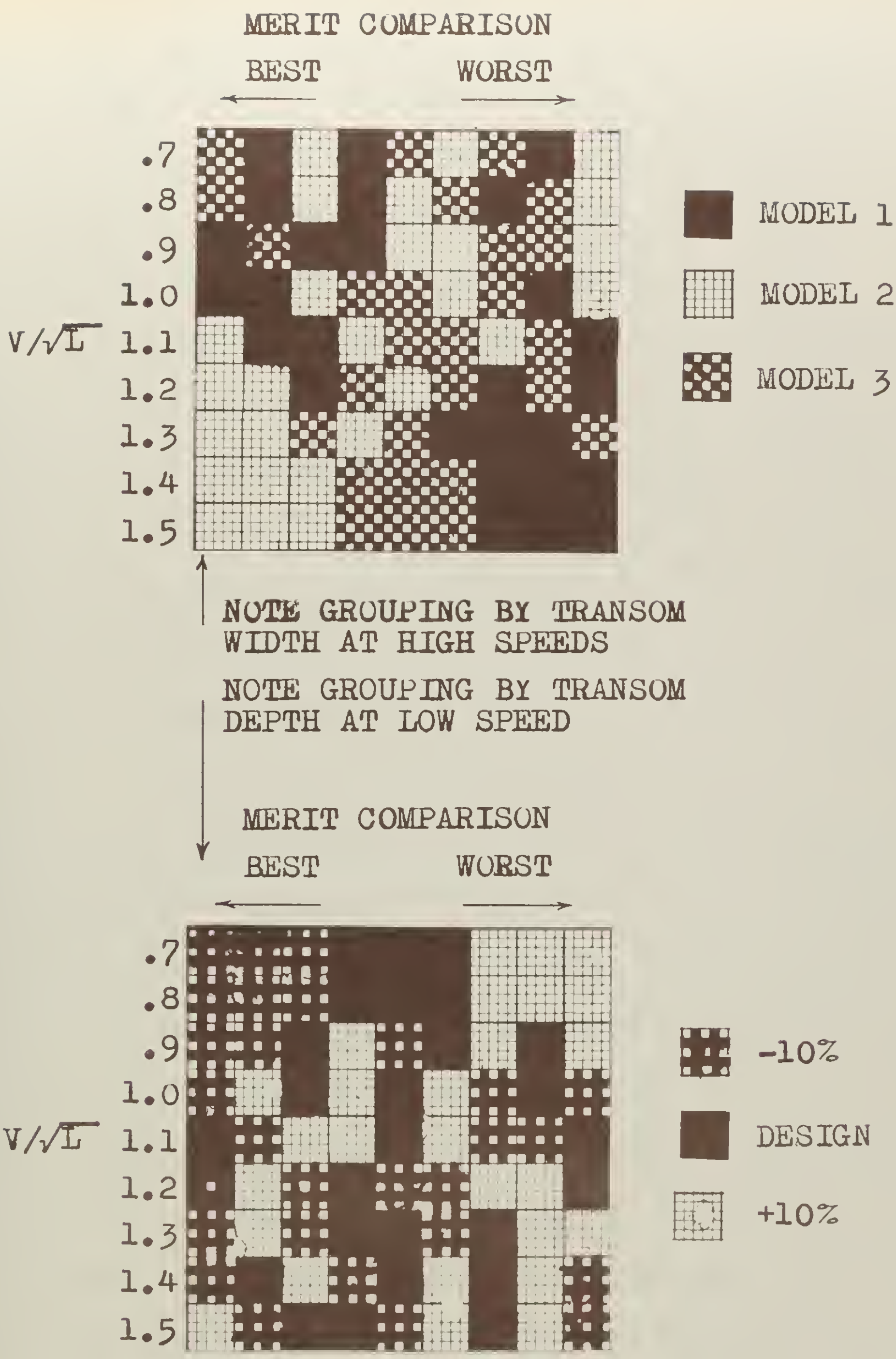


COMPARISON OF MEASURED EHP
AND COMPUTED TAYLOR EHP
MODEL 1
MODEL 2
MODEL 3
+10
DESIGN
-10
RELATIVE $\frac{EHP}{EHP_T}$
3
2
1
0
-1
0.6
0.8
1.0
1.2
1.4
1.6
$V/\sqrt{L}$

FIG-34

width transom performs significantly better than the other models at its design and -10% displacements.

In order to compare the relative merits of each model and displacement variation with respect to the transom parameters of depth and width, figure 35 was developed. The merit scale is based on the position of a particular model or a particular displacement in figure 34. The upper plot of figure 35 compares each model independent of displacement. As each model has essentially the same transom width ratio for it's three displacements, this plot shows the relative merit of the 1/2, 3/4, and 1.0 width transom. The lower plot compares the three displacements independent of model number. In a like manner this allows a comparison of the significance of transom depth with relation to the speed.



MERIT COMPARISON
BEST
WORST
.7
.8
.9
1.0
V/√L 1.1
1.2
1.3
1.4
1.5
MODEL 1
MODEL 2
MODEL 3
NOTE GROUPING BY TRANSOM WIDTH AT HIGH SPEEDS
NOTE GROUPING BY TRANSOM DEPTH AT LOW SPEED
MERIT COMPARISON
BEST
WORST
.7
.8
.9
1.0
V/√L 1.1
1.2
1.3
1.4
1.5
-10%
DESIGN
+10%

FIG-35

CONCLUSIONS AND RECOMMENDATIONS

The merit comparison of figure 35 provides the best source of information to develop generalizations on the effect of transom width and depth parameters. At the cruising speed range of 14 to 19 knots, $V/\sqrt{L} \sim$ from 0.7 to 0.9, it is desirable to have a low transom immersion independent of the transom width. At the high speeds above 25 knots, $V/\sqrt{L} = 1.3$, a wide transom tends to delay the onset of squat resulting in a lower resistance hull form. The depth ratio has only a small effect in the high speed range and, therefore, low depth should be used whenever practiable. At $V/\sqrt{L}$ above 1.3 the medium width transom, $T_W/B_X = 0.75$, is only moderately outperformed by the full width transom. There appears to be a trade-off involved in making the transom wider and reducing squat at high speeds and increasing the wetted surface at the same time thus increasing the resistance at the low speeds.

The first attempt to design an optimum hull using the resistance regression analysis equation (17) resulted in $T_W/B_X = 0.15$ and $f_A = 0.15$. In order to yield an acceptable transom the T_W/B_X was increased to 0.45 with a predicted increase in resistance. The results of the present report's 3 models, however, indicate that a transom with $f_A = 0.10$ and $T_W/B_X = 0.75$ with the resulting low transom immersion would have

produced a better stern. It is recommended by the authors that the regression analysis equation be modified to the extent that f_A be eliminated from the equation and given a constant value between 0.08-0.10 to agree with this study, the 1932 EMB report (1) and the testing conducted at AEW (3). In place of f_A, T_T/T_X should be inserted to account for the low-speed effects of transom immersion. It is also felt that on the basis of this study the regression analysis cannot be used to quantitatively predict resistance for a given hull form. On the other hand, valuable information may possibly be derived if the regression is used to predict resistance trends for single coefficient variations.

With regard to wedges, a study should be made to possibly correlate lift as a function of the angle through which the water travels along a buttock as it approaches the transom and flows past the wedge. The authors investigation of this optimum angle at the $\frac{1}{4}$ beam buttock calculated the angle change of the water to be $\approx 27^\circ$, 4°-5° change on the buttock and $\approx 22^\circ$ angle on the wedge, for the best wedge at a $V/\sqrt{L}$ = 1.4 on all three models. Final selection of a wedge (or flap) should be based on self-propelled tests, however, as wedge effects increase when in the propeller race.

As noted in the special trim test a wedge is an actual lift device which reduces displacement at $V/\sqrt{L} > 1.2$ significantly lowering resistance.

The authors feel in closing that a detailed systematic study should be conducted in the area of transom sterns in light of their expanding demand, with special attention to the wide beam and low immersion transom fitted with an adjustable flap at the stern to accomodate all speed conditions. The authors have prepared an outline of a suggested experimental program for this purpose which is presented in Appendix 3.

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16. M.Gertler, "A Reanalysis of the Original Test Data for the Taylor Standard Series", David Taylor Model Basin Report 806, March 1954.

17. Dr. F. H. Todd, G.R. Friedenberg, and G.R. Stuntz, "Design of Optimum Destroyer Forms Using Regression Analysis Equations", Progress Report on DTMB Report C-2233, 1967.

APPENDIX 1

STATISTICAL ANALYSIS

STATISTICAL STUDY OF NSRDC 1932 REPORT (REF. 1)

FOR DETAILS SEE REF. 7, PAGES 266-271

FOR 6 KNOTS – x_{ij} = MODEL RESISTANCE – lbs

AREA RATIO – f_a

x_{ij}	0 $j=1$	0.10 $j=2$	0.20 $j=3$	S_i	$\bar{x}_i$	δ_i	δ_i^2
BUTTOCK SHAPE: HOLLOW $i=1$	19.85	19.30	20.40	59.55	19.85	-0.16	0.0256
NORMAL $i=2$	20.15	18.00	20.25	58.40	19.46	-0.55	0.3025
FULL $i=3$	21.50	20.10	20.55	62.15	20.72	+0.71	0.5041
S_j	61.50	57.40	61.20	s=180.10		$\Sigma \delta_i^2 = 0.8322$	
$\bar{x}_j$	20.50	19.13	20.40		$\bar{x}$=20.01		
δ_j	0.49	-0.88	0.39				
δ_j^2	0.2401	0.7744	0.1521	$\Sigma \delta_j^2 = 1.1666$			

x_{ij}^2	$j=1$	$j=2$	$j=3$	SS_i
$i=1$	394.02	372.49	416.16	1182.67
$i=2$	406.02	324.00	410.06	1140.08
$i=3$	462.25	404.01	422.30	1288.56
SS_j	1262.29	1100.50	1248.52	SS=3,611.31

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	FOR F-TEST	$F_{2,4,.05}$	$F_{2,4,0.10}$
BUTTOCK SHAPE	2.46	2	1.230	3.596	6.944	4.325
f_a	3.48	2	1.740	5.088	6.944	4.325
ERROR	1.37	4	0.342			
TOTAL	7.31	8				

∴ AT 5% LEVEL, ACCEPT BOTH H_0 & H_0', NEITHER SIGNIFICANT

AT 10% LEVEL, REJECT H_0', SIGNIFICANT CHANGE DUE TO f_a

FOR 7.5 KNOTS

AREA RATIO – f_A

	X_{ij}	0 $j=1$	0.10 $j=2$	0.20 $j=3$	S_i	$\bar{X}_i$	δ_i	δ_i^2
BUTTOCK SHAPE	HOLLOW $i=1$	36.30	34.60	35.70	106.60	35.53	−0.49	0.2401
	NORMAL $i=2$	36.75	34.80	35.60	107.15	35.72	−0.30	0.0900
	FULL $i=3$	39.00	36.00	35.40	110.40	36.80	+0.78	0.6084
	S_j	112.05	105.40	106.70	$S=324.15$		$\Sigma\delta_i^2=0.9385$	
	$\bar{X}_j$	37.35	35.13	35.57		$\bar{X}=36.02$		
	δ_j	1.33	−0.89	−0.45				
	δ_j^2	1.7689	0.7921	0.2025	$\Sigma\delta_j^2=2.7635$			

X_{ij}^2	$j=1$	$j=2$	$j=3$	SS_i
$i=1$	1317.69	1197.16	1274.49	3789.34
$i=2$	1350.56	1211.04	1267.36	3828.96
$i=3$	1521.00	1296.00	1253.16	4070.16
SS_j	4189.25	3704.20	3795.01	$SS=11,688.46$

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	FOR F-TEST	$F_{2,4,.05}$	$F_{2,4,0.10}$
BUTTOCK SHAPE	2.81	2	1.405	2.187	6.944	4.325
f_a	8.28	2	4.140	4.787	6.944	4.325
ERROR	2.57	4	0.642			
TOTAL	13.66	8				

∴ AT 5% LEVEL, ACCEPT BOTH H_0 & H_0', NEITHER SIGNIFICANT

AT 10% LEVEL, REJECT H_0', SIGNIFICANT CHANGE DUE TO f_A

FOR 9 KNOTS

AREA RATIO – f_A

x_{ij}	0 $j=1$	0.10 $j=2$	0.20 $j=3$	S_i	$\bar{x}_i$	δ_i	δ_i^2
BUTTOCK SHAPE: HOLLOW $i=1$	50.35	46.55	47.00	143.90	47.97	−0.73	0.5329
NORMAL $i=2$	49.95	47.10	48.25	145.30	48.43	−0.27	0.0729
FULL $i=3$	52.95	48.75	47.40	149.10	49.70	+1.00	1.000
S_j	153.25	142.40	142.65	$S=438.30$		$\Sigma\delta_i^2 = 1.6058$	
$\bar{x}_j$	51.08	47.47	47.55		$\bar{x}=48.70$		
δ_j	2.38	−1.23	−1.15				
δ_j^2	5.6644	1.5129	1.3225	$\Sigma\delta_j^2 = 8.4998$			

x_{ij}^2	$j=1$	$j=2$	$j=3$	SS_i
$i=1$	2525.12	2166.90	2209.00	6911.02
$i=2$	2495.00	2218.41	2328.06	7041.47
$i=3$	2803.70	2376.56	2246.76	7427.02
SS_j	7833.82	6761.87	6783.82	$SS = 21,379.51$

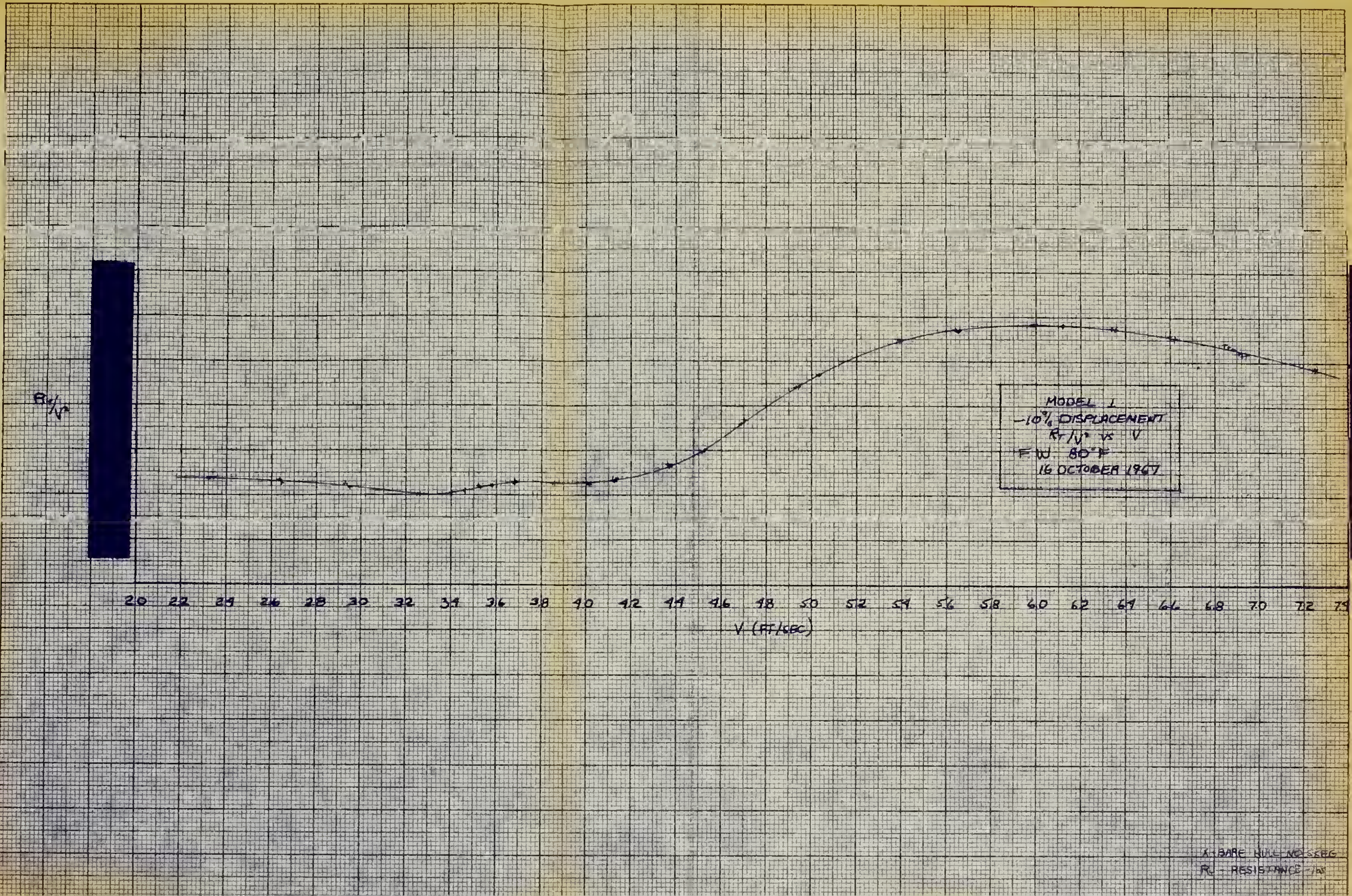
SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	FOR F-TEST	$F_{2,4,.05}$	$F_{2,4,0.10}$
BUTTOCK SHAPE	4.83	2	2.415	2.477	6.944	4.325
f_A	25.57	2	12.785	13.113	6.944	4.325
ERROR	3.90	4	0.975			
TOTAL	34.30	8				

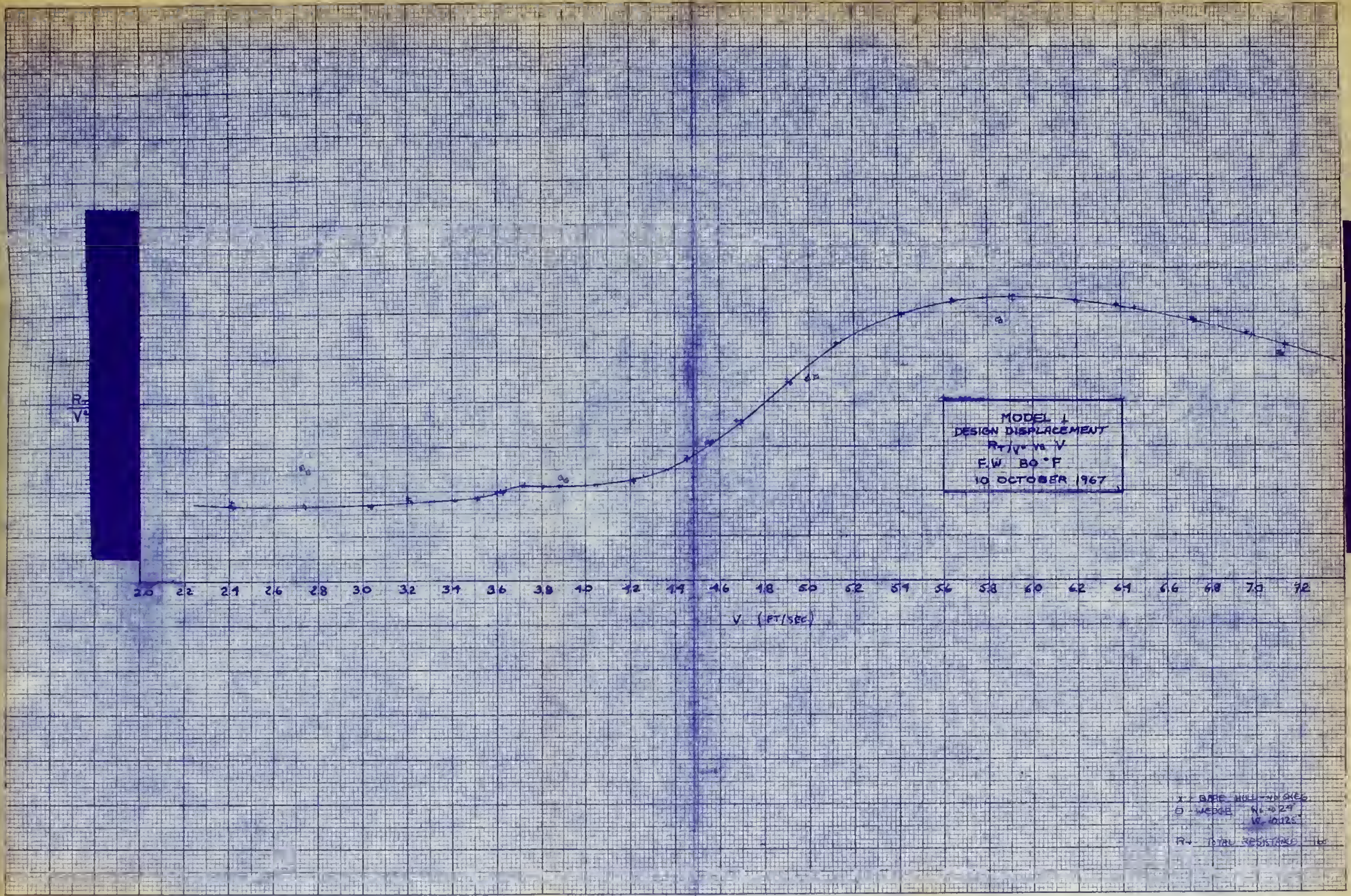
∴ AT 5% LEVEL, REJECT H_0', SIGNIFICANT CHANGE DUE TO f_A

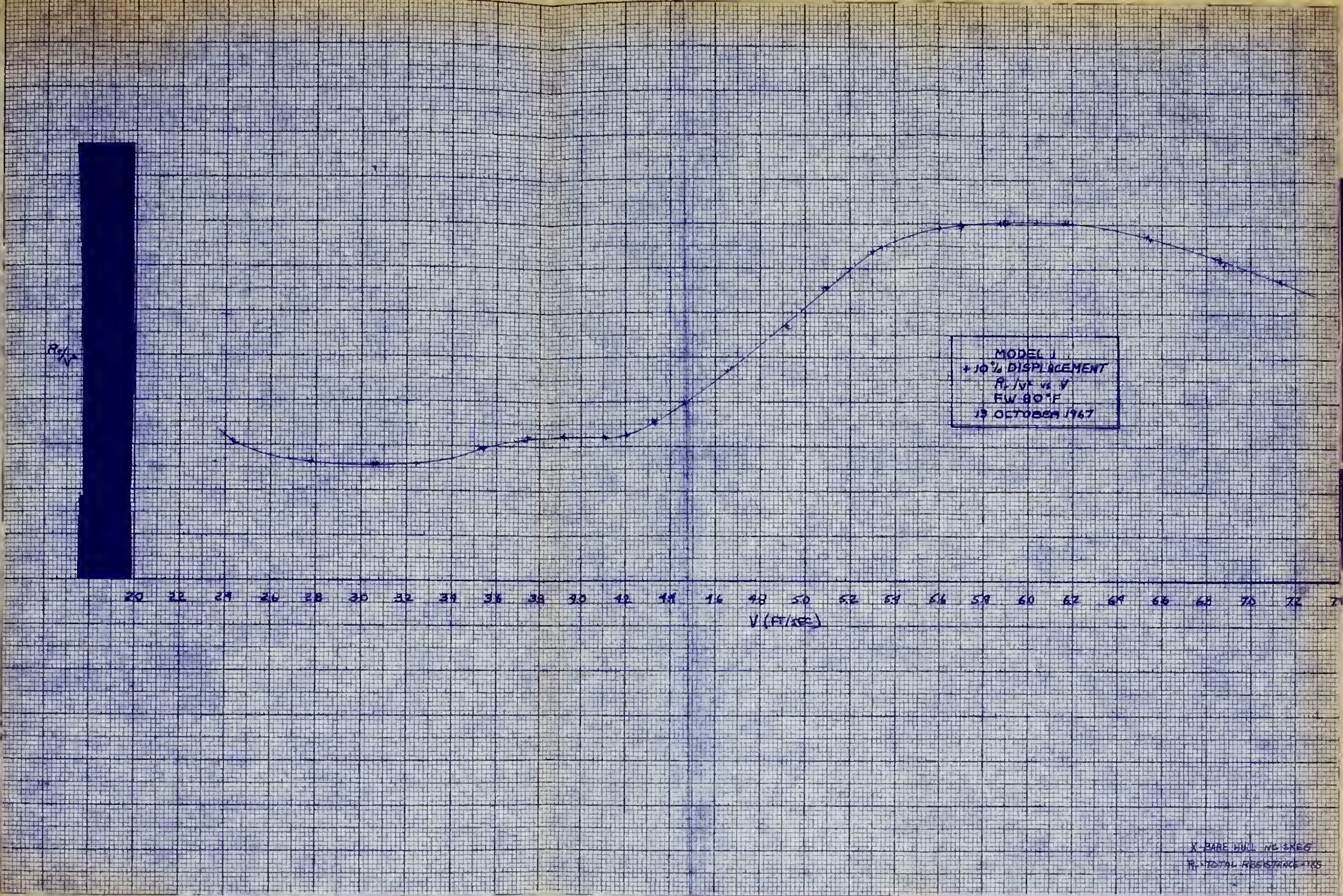
AT 10% LEVEL, " " " " "

APPENDIX 2

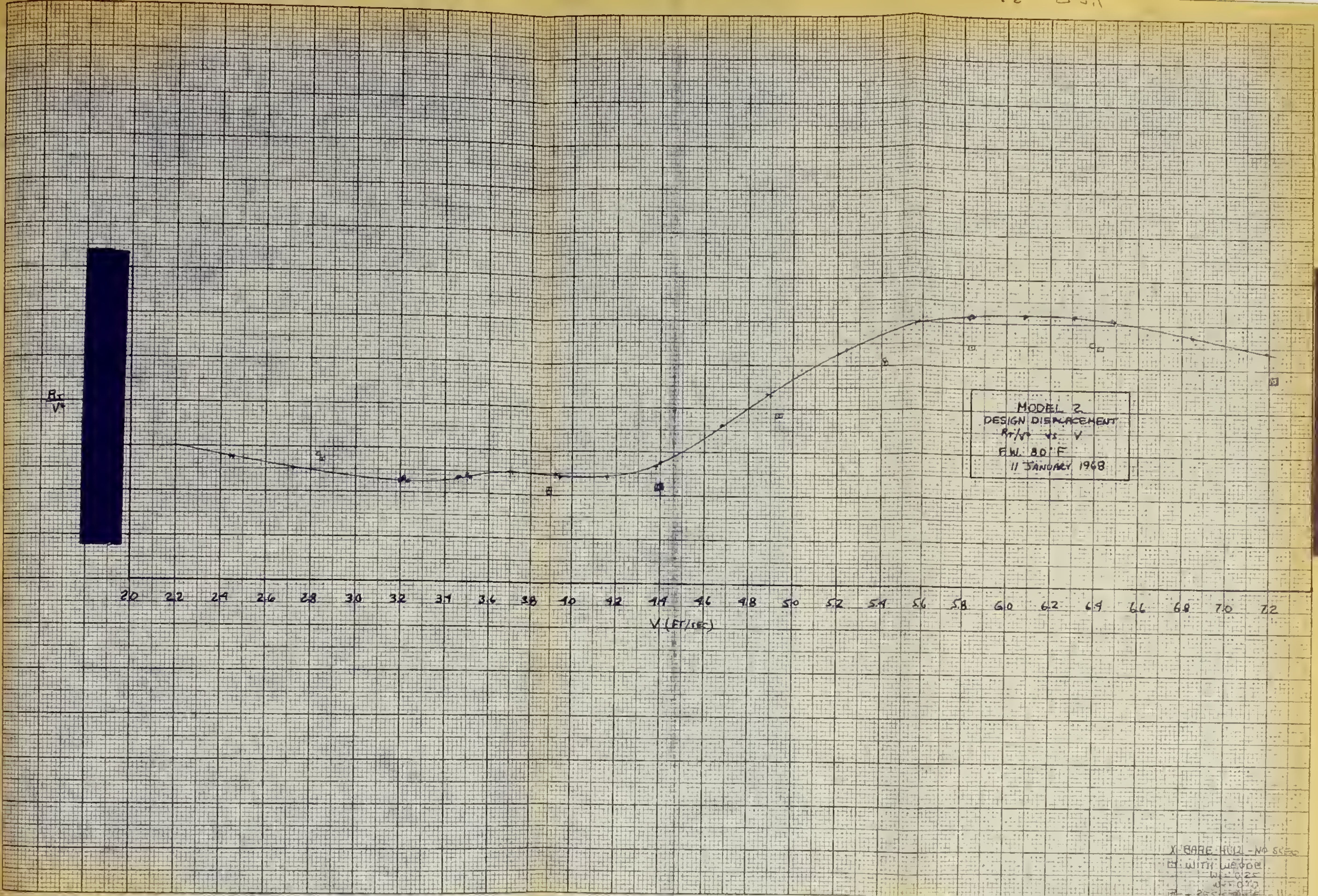
CURVES OF R_T/V^2 VS V


R_T/V^2
[redacted]
2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8 4.0 4.2 4.4 4.6 4.8 5.0 5.2 5.4 5.6 5.8 6.0 6.2 6.4 6.6 6.8 7.0 7.2 7.4
V (FT/SEC)
MODEL I
-10% DISPLACEMENT
R_T/V^2 vs V
F.W. 80°F
16 OCTOBER 1967
X - BARE HULL NO SKEG
R - RESISTANCE - lbs

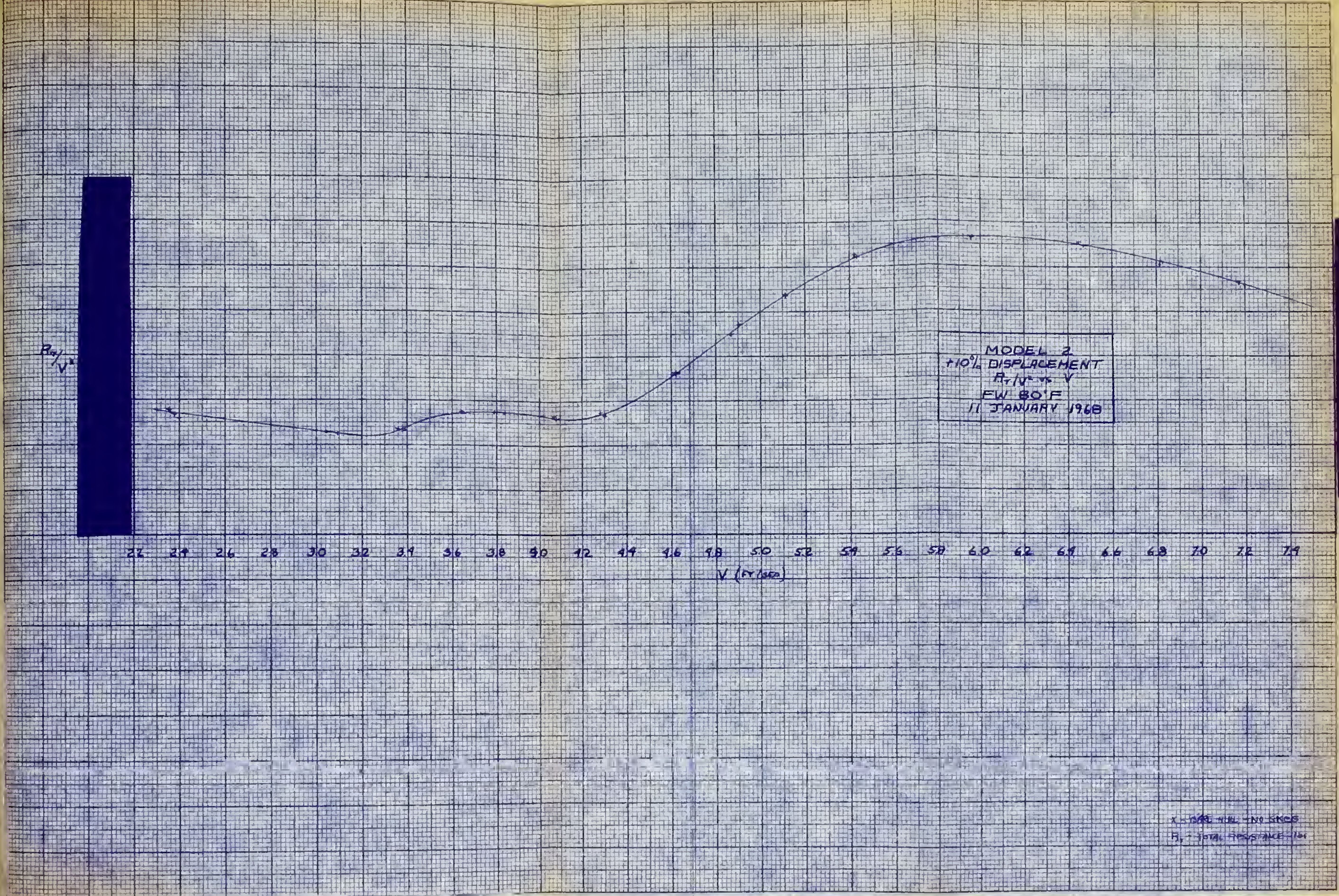

MODEL 1
DESIGN DISPLACEMENT
RT/V² vs V
F.W. 80°F
10 OCTOBER 1967
V (FT/SEC)
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
4.2
4.4
4.6
4.8
5.0
5.2
5.4
5.6
5.8
6.0
6.2
6.4
6.6
6.8
7.0
7.2
x - BARE HULL - NO SKEG
⊖ - WEDGE
RT - TOTAL RESISTANCE lb



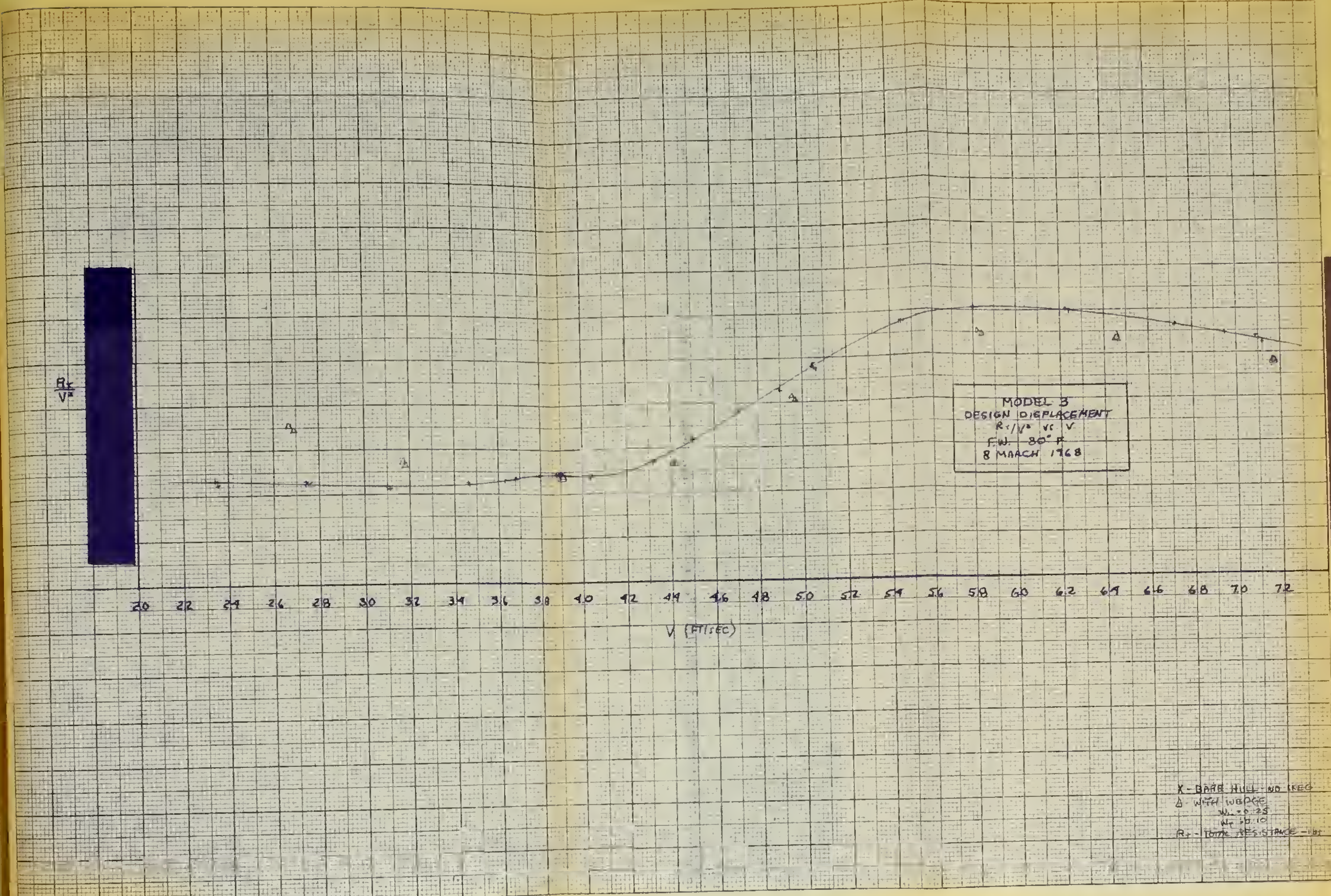
R_t/V^2
[redacted]
MODEL 1
+10% DISPLACEMENT
R_t/V^2 vs V
FW 80°F
13 OCTOBER 1967
20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74
V (FT/SEC)
X-BARE HULL NO SKEG
R_t-TOTAL RESISTANCE-LBS



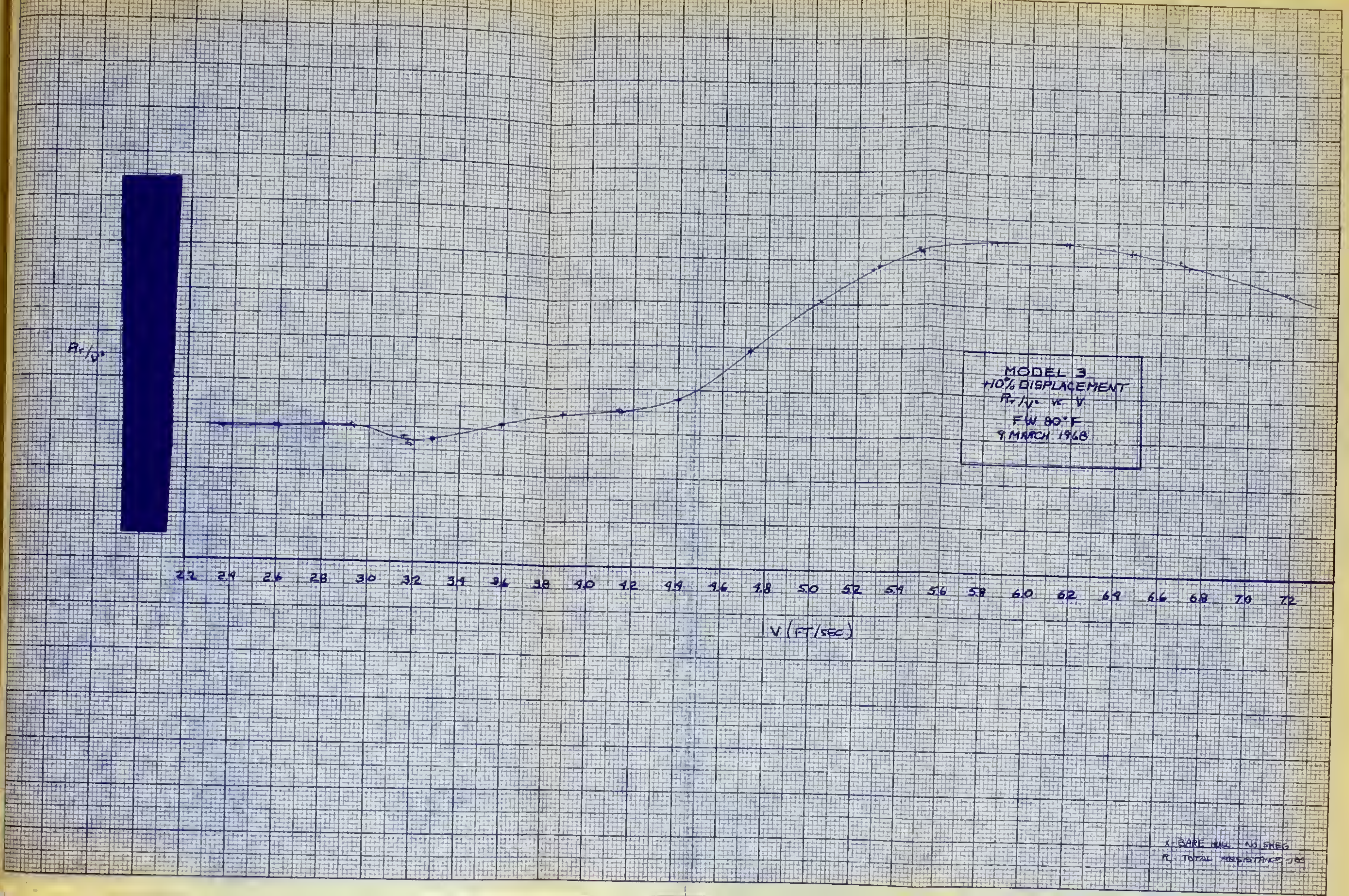
$\frac{R_T}{V^2}$
[redacted]
2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8 4.0 4.2 4.4 4.6 4.8 5.0 5.2 5.4 5.6 5.8 6.0 6.2 6.4 6.6 6.8 7.0 7.2
V (FT/SEC)
MODEL 2
DESIGN DISPLACEMENT
R_T/V^2 vs. V
F.W. 80°F
11 JANUARY 1968
X BARE HULL - NO SSES
□ WITH WEDGE



MODEL 2
+10% DISPLACEMENT
R_T/V^2 vs V
FW 80°F
11 JANUARY 1968
R_T/V^2
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
4.2
4.4
4.6
4.8
5.0
5.2
5.4
5.6
5.8
6.0
6.2
6.4
6.6
6.8
7.0
7.2
7.4
V (FT/SEC)
X - BARE HULL - NO SKEGS
R_T - TOTAL RESISTANCE - lbs



MODEL 3
DESIGN DISPLACEMENT
F.W. 80° F
8 MARCH 1968
V (FT/SEC)
2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8 4.0 4.2 4.4 4.6 4.8 5.0 5.2 5.4 5.6 5.8 6.0 6.2 6.4 6.6 6.8 7.0 7.2


R_T/V^2
2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8 4.0 4.2 4.4 4.6 4.8 5.0 5.2 5.4 5.6 5.8 6.0 6.2 6.4 6.6 6.8 7.0 7.2
V (FT/SEC)
MODEL 3
+10% DISPLACEMENT
R_T/V^2 vs V
F.W. 80°F
9 MARCH 1968
X - BARE
SKEG
R - TOTAL

APPENDIX 3

SUGGESTED EXPERIMENTAL PROGRAM

SUGGESTED EXPERIMENTAL PROGRAM

In order to foster future study in the area of transom stern design, the authors suggest the following experimental and analytical procedure to be conducted as it relates to destroyer design.

Hull Selection

It was brought out by recent studies that given an optimum bow bulb, the interference of stern bow waves greatly effects the optimum depth at transom. Based on the premise that the destroyer under consideration is a high speed ASW ship, it is recommended that a low resistance bow bulb be designed around the bow sonar dome and this forebody be used as the parent for the remainder of the testing.

SUGGESTED TEST PROCEDURE

Step One

Select a series of sterns in which transom width and transom depth can be varied independently. Attempt to hold LCB and C_{P_A} constant and allow center of flotation to vary. The selection of transom coefficients for the first series should permit transom width to range from $0.4B_X$ to $1.0B_X$, with constant transom depth and accepting the change in the transom area ratio. The second series is simply the reverse with transom

depth altering no greater than $0.4T_X$ with a constant transom width ratio and the resulting transom area ratio.

Step Two

In order to complete the integrated series and optimize the afterbody, each model should be tested concurrently with a transom flap. By systematically adjusting flap slope at each speed an optimum angle can be determined to produce minimum resistance.

ANALYTICAL STUDY

Step One

A prediction of resistance based on a wave analysis for an integrated bulbous bow / transom stern ship could be accomplished to determine the optimum configuration and then compared with the actual test results.

Step Two

A study using a regression analysis technique with more hull parameters than reported in (4) plus the addition of T_T/T_X' could also lend itself to a similar comparison.

Step Three

An investigation of the desired lift to be produced by a particular flap angle as a function of its

induced pressure distribution would complement a trim study conducted under the afore-mentioned experimental step two.

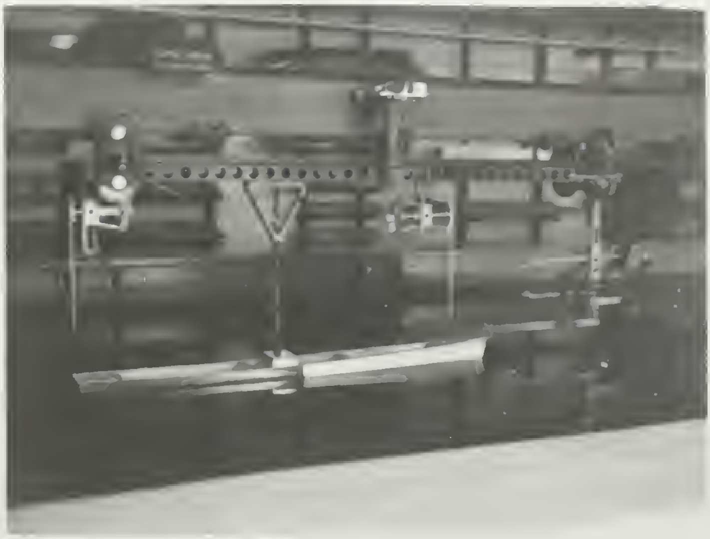
During a preliminary warship design course at Webb Institute, the authors developed lines for a destroyer escort embodying an unusual integrated bulbous bow / sonar dome configuration with a wide low depth of immersion transom stern. The transom coefficients coincide with the best resistance features of Model's 2 and 3 of this report. Therefore in order to initiate this study, the authors submit the developed lines as a possible parent hull design.

APPENDIX 4

PHOTOGRAPHIC ILLUSTRATIONS

MODEL 1 - PARENT HULL $T_W/B_X = 0.558$

MODEL 2 - $T_W/B_X = 1.0$



MODEL 3 SHOWN WITH
DYNAMOMETER AND TRIM
GAGES ATTACHED.

MODEL 3 - $T_W/B_X = 0.75$

WEDGE HEIGHT AND SLOPE VARIATIONS

MODEL 1
DESIGN WEDGE

MODEL 3
DESIGN WEDGE

MODEL 2
DESIGN WEDGE